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AN INVESTIGATION OF APPENDAGE DRAG

by

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SHIP PERFORMANCE DEPARTMENT

AN INVESTIGATION OF APPENDAGE DRAG

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magnitude.

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NOMENCLATURE

c	chord length
C_f	coefficient of flat plate friction
C_p	pressure drag coefficient
D	diameter
L	length of appendage
R_B	base resistance due to bluntness of trailing edge
R_f	flatplate frictional resistance
R_{INT}	added resistance due to intersection
R_p	pressure or separation resistance
R_{VA}	velocity augmented resistance
S	planform area of one side of appendage
S_B	projected area of base or trailing edge
t	thickness
t_B	thickness of base or trailing edge
V	velocity
α	cross flow angle (angle between hull and appendage)
ν	kinematic viscosity
ρ	mass density

ABSTRACT

The purpose of this report is to provide information about the resistance, interaction and scaling of appendages. A calculation procedure is developed that can be used to compute the Reynolds number dependent components of appendage drag. A correlation is made between the calculated values of drag and data obtained from bare hull and appended ship-model resistance tests. This correlation indicates that the mathematical model is an effective means of predicting the viscous drag of appendages and that the added drag due to pressure as well as interaction between appendages and the hull form is of a small order of magnitude.

ADMINISTRATIVE INFORMATION

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INTRODUCTION

Ship appendages refer usually to elements outside the main hull, such as shafting, shaft supporting struts and bossings, power transmission pods and struts, bilge keels and control surfaces. It has been common practice to measure the drag of these appendages as the difference in drag when conducting resistance tests with a ship-model in the bare hull and the appended condition. These measurements provide a gross assessment of the total drag of appendages plus interaction effects for a particular design but they do not give detailed drag data for each appendage, nor interactions between hull and appendages. The designer does not have sufficient information to improve designs where the combined drag is unduly high. Furthermore the extrapolation, from model to full-scale, of appendage drag is questionable at best.

A procedure for designing appendages was presented in 1953 by Philip Mandel[1]. In his summary, Mandel states that scale effects of appendage-resistance "...are important not only in accounting for part of any discrepancies between model power predictions and full-scale results but also in establishing the validity of comparative model testing conducted for the purpose of evaluating competitive appendages. Fundamental studies and tests of individual appendages over a large range of Reynolds numbers are needed for this purpose." In 1957, E. P. Clement conducted such a study using appendages from a planing boat[2]. Clement concluded that the resistance predictions based on previous model tests were too high by about 2.9% when they were compared with his tests. He further concluded that this error was a scale effect due to the fact that below a Reynolds number of 10^6 the extrapolator used with the Schoenherr friction line was not steep enough. In 1966, Hadler[3] developed mathematical expressions for predicting the drag of planing boat appendages and used Clement's work to determine the accuracy of his method.

References are listed on page 55.

The present task would appear to be to verify if the works by Clement and Hadler can be applied to displacement type surface-ships. The major problem encountered in this area is in predicting the flow in way of the appendages. Whereas in a planing boat, it may be assumed that the flow is parallel to the bottom of the hull and has the same magnitude as the boat speed, this is not necessarily the case for displacement ships.

This report will discuss ways of estimating the magnitude and direction of the velocity in way of the appendages. Then a mathematical model will be developed for estimating the Reynolds number dependent drag of the following appendage components:*

1. Rudders,
2. Shaft support struts,
3. Stabilizer fins,
4. Intermediate and main shafts,
5. Sterntube bossings,
6. Intermediate and main strut barrels,
7. Bilge Keels, and
8. Skegs.

The results obtained from the mathematical model are then correlated with model test data and there is a discussion of the induced forces and the interaction between the appendages and the hull.

* It should be noted that although this report does not cover such appendages as power transmission pods or right angle drive units, information regarding these appendages may be found in References 4 and 5. It is hoped, that at a later date expressions will be developed for these appendages as there would appear to be quite a demand for this information in the future.

MATHEMATICAL EXPRESSIONS OF APPENDAGE DRAG

In the development of mathematical expressions that can predict the drag of the aforementioned appendages it was necessary to make assumptions so that the calculations could be made with relative ease and still be applicable. The first major assumption is that the appendages can be divided into their component parts, the drag of each component being calculated separately and therefore, the total appendage drag is equal to the sum of the drag of each appendage. The second major assumption is that the drag of the appendages is considered to be viscous in nature. (These assumptions will be discussed in further detail later in the text.) Other assumptions will be discussed for each case and specific references are noted next to each expression.

THE APPENDAGE COMPONENTS

The appendages considered herein are broken down into the following groups:

- Group I = Rudders, struts, and stabilizer fins;
- Group II = Sterntube bossings, intermediate shafts, main shafts, and intermediate strut barrels;
- Group III = Main strut barrels;
- Group IV = Bilge keels and skegs.

Groups I and II are treated as two-dimensional surfaces; Group III is treated like a body of revolution and Group IV is treated similar to a flat plate friction plane.

VELOCITY – MAGNITUDE AND DIRECTION

In the preliminary design stage, more often than not, the designer can only approximate the velocity at the stern. At present there are no simple

methods for predicting the flow in way of a ship's appendages. The Douglass Aircraft Company, Inc. has developed a computer program for calculating potential flow about arbitrary three-dimensional bodies (Reference 6). The Douglass program has been used successfully in several cases to predict the flow about ship hulls. There has been some success in predicting the pressure distribution over a bow-mounted sonar dome.[7] However, in the early stages of this project, an attempt was made to predict the flow at the stern of a ship, and it was concluded that this method was too expensive, time consuming, and necessitated information which might not necessarily be available to the user during the preliminary design stage of the hull.

For simplicity, if we restrict this investigation to ships with multiscrew propulsion systems that have some type of transom stern with a relatively flat bottom, we may then assume that the wake fraction, for this type of ship, will normally range from zero to eight percent. Therefore, we may use as the local velocity in way of the appendage, the freestream velocity or modify it by a wake fraction (based on data for a similar ship which has previously been tested). It is felt that in terms of percentages, the error due to this assumption would be approximately 0 to 8 percent (at most) of the velocity as measured from a wake survey.*

As for the direction of the local velocity, it is assumed that the struts, skegs, bilge keels, stabilizer fins and rudders align with the flow. Further, the direction of flow past cylindrical bodies such as shafts, sterntube bossings, strut barrels, and fairwaters is assumed to be parallel to the hull and that there is no transverse crossflow. Therefore, the direction of the flow over these appendages can be estimated to be the angle they make (locally) with the hull.

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* This assumes that the velocity error will be no greater than the wake fraction for the hull form.

THE FRICTION FORMULATION

The Schoenherr friction line, (Reference 8), has been used for all friction calculations on the appendages. The numerical values of C_F derived from the Schoenherr formula apply to the viscous component of flat surfaces whereas other friction lines commonly used by naval architects in determining the frictional resistance of ships might incorporate various degrees of a form factor.

Therefore, since the Schoenherr formulation is considered to be a baseline, the expressions used to calculate appendage drag will relate the geometric parameters of the appendage to the corresponding flat plate friction coefficient.

The Schoenherr friction formula may be simplified by the following expression:

$$C_F = 1/(3.46 \log_{10}(Rn) - 5.6)^2 \qquad (1)$$

This approximation is considered to be within $\pm$ 2 percent of the standard Schoenherr formulation.

The formulations are for turbulent flow. However, a correction should be made to account for the fact that the appendages experience a local flow which may be laminar up to a point and then becomes turbulent afterward. The following are the expressions which have been used to obtain the coefficient of friction for all work discussed in this report:

$$C_{F_{Laminar}} = 1.327/\sqrt{Rn} \qquad (2a)$$

$$C_{F_{Turbulent}} = \frac{0.242}{\sqrt{C_F}} + \log_{10}(Rn \cdot C_F), \qquad (2b)$$

$$C_{F_{Transition}} = C_{F_{Turbulent}} - \frac{A}{Rn}, \qquad (2c)$$

$$\text{where } A = \frac{\left(C_{F_{Turbulent}} - C_{F_{Laminar}}\right) Rn}{\left(\begin{array}{l}\text{all taken at the chosen} \\ \text{Reynolds number at transition}\end{array}\right)}.$$

It will be shown later that for the present work on appendages, an appropriate Reynolds number for transition is approximately 5×10^4. Figures 1 and 2 are provided to facilitate the user in obtaining Reynolds numbers and friction coefficients. Figure 1 presents a graphical solution for obtaining Reynolds numbers; a sample problem is shown by the indicated arrows. Figure 2 presents curves of the friction coefficient previously discussed. Transition curves from laminar to turbulent flow are given for $Rn_{Transition} = 5 \times 10^4$; 1×10^5 and 5×10^5. Conditions where "forced turbulence" would be used correspond to the case where the turbulent curve is used for all Reynolds numbers and would be generated by using $Rn_{Transition} = 0.0$.

GROUP I - RUDDERS, STRUTS AND STABILIZER FINS

Group I appendages, as considered herein, are assumed to have streamline sections with a maximum thickness located at 30 to 50 percent of the chord length. They are treated as two-dimensional surfaces which for appendages aligned with the flow appears to be acceptable. This is because experimental work for rudders, for example, reference 10, has shown that the effects of aspect ratio, sweepangle, and tip ending are small for zero angle of attack. Furthermore, it is also assumed that there is no ventilation or cavitation. With all of these simplifying assumptions taken into consideration the total drag can be derived as the sum of the various components usually considered in two-dimensional foil prediction. Expressions for these components such as flat plate friction resistance (R_F),

resistance due to velocity augmentation (R_{VA}), pressure or separation resistance (R_P), added resistance due to an intersection with the hull or a strut barrel (R_{INT}) and the base drag due to a bluntness of the trailing edge (R_B) are presented below.

Reynolds Number Used to Obtain C_F

The Reynolds number used for Group I appendages is a function of velocity, kinematic viscosity and chord length* or,

$$Rn = Vc/\nu, \qquad (3)$$

Flat Plate Friction Resistance

The expression used to obtain the flat plate friction resistance is as follows:

$$R_F = 1/2 \;\rho S V^2 (2C_F), \qquad (4)$$

Resistance Due to Velocity Augmentation

The mean average velocity around a symmetrical foil section is higher than that of the undisturbed flow. The added resistance due to this velocity augmentation is given by:

$$R_{VA} = \rho 1/2 \; SV^2 \; (2C_F) \quad (2t/c), \qquad (5)$$

Pressure or Separation Resistance

The pressure or separation resistance is a component originating due to the lack of pressure recovery associated with boundary layer thickness and/

* For the work presented in this report, the maximum chord length was used when the drag of tapered appendage was to be calculated.

or separation along the afterbody of foil and strut sections. The expression for approximating the pressure drag is given as follows:

$$R_P = 1/2\ \rho S V^2\ (2C_F)\ 60\ (t/c)^4, \qquad (6)$$

Added Resistance Due to Intersection with Hull or Strut Barrel

The added resistance due to an intersection of any of these appendages with another surface will be treated as if it were an intersection with a flat wall. It is speculated that, "When a wing or strut adjoins a wall (or an end plate), the boundary layers of both; the wind and the wall, join each other. Subjected to the pressure gradient along the rear of the foil section; the boundary layer is further retarded; and additional pressure drag (i.e., interference drag) arises."[11] It should be noted that for very thin sections ($t/c < .08$, this interference drag might become negative. The expression for estimating this drag component is given below:

$$R_{INT} = 1/2\ \rho V^2 t^2 \left[0.75\ (t/c) - 0.0003/(t/c)^2\right] \qquad (7)$$

Base Drag Due to Bluntness of Trailing Edge

The base drag of foil section with blunt trailing edges may be approximated with the following expression.

$$R_B = 1/2\rho\ \ S_B V^2 \left[0.135/^3\sqrt{C_F(c\ /t_B)},\right] \qquad (8)$$

GROUP II – SHAFTING, STERNTUBE BOSSINGS AND INTERMEDIATE STRUT BARRELS

In order to estimate the drag of the shafting, it was necessary to divide this appendage into the following sections: (1) Intermediate shaft (between the sterntube bossing and the intermediate strut barrel), and (2) main shaft (between the intermediate strut barrel and the main

strut barrel). The resistance components of Group II appendages are the frictional resistance (R_F) and the pressure resistance corrected for crossflow (R_P).

Friction Resistance and Reynolds Number

The Reynolds number used in estimating the frictional drag is based on the appendage length along the longitudinal axis. Therefore,

$$Rn = \frac{VL_2}{\nu} \qquad (9)$$

where

L = length of appendage along the longitudinal axis (for sterntube bossings, the length is taken to the intersection with the hull along the shaft centerline).

The friction resistance may be determined by the following expression.

$$R_F = 1/2 \;\rho LDV^2 \;\pi C_F, \qquad (10)$$

Pressure Resistance Corrected for Crossflow

The expression used to estimate the pressure drag has been taken from a derivation proposed by Hoerner (reference 11). The general form of the equation is:

$$R_P = 1/2 \;\rho LDV^2 \;C_P \;\sin^3\alpha \qquad (11)$$

The pressure drag coefficient (C_P) may be further defined for non-cavitating and cavitating flows. The proposed definition of C_P follows from work presented in reference 11, page 10-8, Figure 15a. This figure presents drag coefficients as a function of cavitation number for flows that are

above and below the critical Reynolds number for separation. The parameters used to describe the flow are Reynolds number (Rn) and cavitation number (σ),

$$Rn = \frac{VD_t}{\nu} \tag{12}$$

$$\sigma = (P_{ambi} - P_{vap})/(1/2\ \rho\ V^2) \tag{13}$$

where

P_{ambi} = ambient pressure acting at the centroid of the appendage,

P_{vap} = vapor pressure of the surrounding fluid.

The expressions for the pressure drag coefficient represent the aforementioned curves in reference 11 in polynomial form and are given below for various flow conditions.

Non-Cavitating Flows

$Rn < 5 \times 10^5$ and $\sigma > 2.5$,

$C_p = 1.17$

$Rn > 5 \times 10^5$ and $\sigma > 2.5$,

$C_p = 0.50$

Cavitating Flows

$Rn < 5 \times 10^5$ and $\sigma < 2.5$,

$C_p = .5 + .5\sigma - .052\ \sigma^2 + .046\ \sigma^3 - .061\ \sigma^4 + .014\ \sigma^5$,

$Rn > 5 \times 10^5$ and $2.1 < \sigma < 2.5$,

$C_p = 6.125 - 2.25\ \sigma$,

$Rn > 5 \times 10^5$ and < 2.1,

$C_p = .5 + .5\sigma - .039\ \sigma^2 + .006\ \sigma^3$.

GROUP III - MAIN STRUT BARRELS

The components of a main strut barrel are:

(a) strut barrel,

(b) propeller hub,

(c) fairwater.

These components together are considered one unit.

The components of resistance for these appendages are friction resistance (R_F), pressure resistance corrected for crossflow (R_P) and the base drag due to the bluntness of the fairwater trailing tip (R_B). The expressions used to estimate the resistance due to friction and pressure are the same as the ones for Group II appendages (Equations (9) through (13)).

Base Drag Due to Bluntness of Fairwater-Ending

According to Hoerner, the base drag of three dimensional bodies very similar to the fairwater (projectiles, fuselages and elipsoids for example) is found to depend largely on the length of the forebody, its surface conditions, and the ratio of base to body diameter. The expression used to estimate the resistance due to the bluntness of the fairwater-ending is:

$$R_B = \frac{\rho}{2} V^2 \frac{\pi}{4} D^2 \left[0.029 \, (D_B/D)^3 / (2\sqrt{C_F(L/D)})\right] \quad (14)$$

where

D = maximum diameter of appendage,

D_B = diameter of base (see above),

L = length of appendage along the longitudinal axis if blunt or rounded trailing end, use the extended length i.e., the length the appendage would be if it were not blunt.

GROUP IV - BILGE KEELS AND SKEGS

The resistance of bilge keels and skegs is treated similar to the drag of a flat plate. This assumes that these appendages are aligned with the flow. It should be noted that, generally, skegs are considered as an integral part of the bare hull form and not as a separate appendage. The expression for estimating the resistance of this group of appendages is,

$$R = 1/2 \; SV^2 \; C_F, \tag{15}$$

where

S = wetted surface area of the appendage minus the wetted surface area of that part of the hull that has been covered up by the appendage. By taking the wetted surface in this manner, the loss of bare hull friction drag due to a net loss of wetted surface on the bare hull can be compensated for.

The Reynolds number to be used to obtain the flat plate friction coefficient is a function of the velocity, length of appendage, and kinematic viscosity, as follows:

$$Rn = \frac{VL}{\nu}. \tag{16}$$

"APPEND" A COMPUTER PROGRAM OF THE MATHEMATICAL MODEL

The expressions derived in the previous section for calculating the drag of various appendages have been used as the basis for a computer routine named APPEND. Details of the computer program are presented in Appendices I through III with the routine/algorithm in Fortran presented in Appendix I, input format and output format in Appendices II and III, respectively.

CORRELATION OF THE MATHEMATICAL MODEL WITH MODEL TESTS

In the presentation of any calculation method, it would be most desirable if the expressions could be proven out by experimental data. For the case of appendages, this would involve the testing of various sizes (scale effect), shapes, and combinations with one another (interactions). However, it was not possible to conduct such an experimental program for this study. It was necessary, therefore, to simulate a data base which could substitute for the test program.

The decision was made to make use of the results of previous model tests conducted by the Naval Ship Research and Development Center. This method involved the selection of fourteen ship-models that had been tested in the bare hull and appended modes for resistance. The drag of the appendages as a group was then obtained from the difference in resistance of the two modes and compared to the results obtained by using the expressions presented herein. A fairing of the data has been made in order to facilitate general comparisons.

A BRIEF DESCRIPTION OF THE SHIP-MODELS

In general, the fourteen ship-models chosen for this study were of the twin screw propulsion type and represent three basic hull forms with

transom type sterns. Tables I and II present a more detailed description of the hull forms and their appendages.

PRESENTATION OF MODEL DATA

As stated previously, it is most desirable to present some experimental data in order to verify a mathematical model. Keeping in mind that the mathematical model presented herein is supposed to represent the Reynolds number dependent components of the appendage drag, then the data should be presented in such a manner so as to describe visually the answers to the following questions. First, and most important, are the expressions able to predict within a reasonable tolerance the Reynolds number dependent drag of the various appendages, and second, what are the possible sources of error inherent to the mathematical model and how can they be compensated for? The data are presented, therefore, in two ways in order to determine if the answers to the above questions are just a function of the individual appendage suit in question or if there are general trends which can be applied to any appendage suit.

Figure 3 presents the values of appendage drag (in coefficient form) as calculated from the mathematical model using both a friction line based on forced turbulence at the lower Reynolds numbers and on a transition Reynolds number equal to 5×10^4 (these friction lines may be seen in Figure 2). Also presented in Figure 3 are the appendage drag data obtained from model tests as previously described. The differences in model appendage drag coefficient for various hull forms of the same designation, e.g. three 3-D forms, are due to differences in the models not readily apparent from the descriptive parameters listed in Tables I and II. The predicted values of Reynolds number dependent appendage resistance appear to be in close agreement with the model data except where "humps" appear. To further investigate this phenomena, Figure 4 has been prepared. It presents the difference between the calculated values

TABLE I

The Hull Forms

Hull Coefficient	Name of Coefficient*	TYPE 1**	TYPE 2	TYPE 3
C_B	Block Coefficient	.61	.66	.48
C_P	Longitudinal Prismatic Coefficient	.63	.67	.59
C_X	Maximum Section Coefficient	.97	.99	.81
C_{WP}	Waterplane Coefficient	.78	.84	.73
C_{PF}	Forebody Prismatic Coefficient	.60	.67	.56
C_{PA}	Afterbody Prismatic Coefficient	.67	.67	.62
C_{PE}	Entrance Prismatic Coefficient	.60	.65	.58
C_{PR}	Run Prismatic Coefficient	.66	.67	.59
C_{VP}	Vertical Prismatic Coefficient	.78	.79	.65
C_{VPA}	Afterbody Vertical Prismatic Coefficient	.72	.69	.62
C_{VPF}	Forebody Vertical Prismatic Coefficient	.88	.93	.78
C_{WPF}	Forebody Waterplane Coefficient	.66	.72	.58
C_{WPA}	Afterbody Waterplane Coefficient	.90	.96	.96

* Formulae for the hull coefficients may be found in Reference 12.

** The numerical values for the hull coefficients for each hull type are the average values for all the designs used.

TABLE II

The Appendage Suits

HULL FORM TYPE	APPEN-DAGE SUIT TYPE	RUDDERS	STRUTS		STABI-LIZER FINS	SHAFTS		STERNTUBE BOSSINGS	STRUT BARRELS		BILGE KEELS	SKEGS
			MAIN	INTER*		MAIN	INNER		MAIN	INTER		
1	A	1	4	-	-	2	-	2	2	-	-	-
1	A	1	4	-	-	2	-	2	2	-	-	-
1	B	2	4	-	-	2	-	2	2	-	-	-
1	B	2	4	-	-	2	-	2	2	-	-	-
2	B	2	4	-	-	2	-	2	2	-	-	-
1	C	2	4	4	-	2	2	2	2	2	-	-
2	D	2	4	4	-	2	2	2	2	2	2	-
3	D	2	4	4	-	2	2	2	2	2	2	-
3	D	2	4	4	-	2	2	2	2	2	2	-
3	D	2	4	4	-	2	2	2	2	2	2	-
3	E	2	4	2	-	2	2	1	2	2	2	-
3	F	2	4	4	4	2	2	1	2	2	2	-
3	G	2	4	2	-	2	2	-	2	2	-	-
3	H	2	4	4	2	2	2	2	2	2	2	-

* INTER is the abbreviation used to signify an intermediate appendage. Its location normally being approximately halfway down the length of the propeller shaft.

(using the transition Reynolds number 5×10^6) and the model data in the form of percent difference and the actual magnitude in pounds. These absolute and relative differences are presented as a function of the model speed non-dimensionalized by the design speed value.

Values of appendage resistance as a percentage of bare hull resistance for the fourteen selected models are presented versus speed-length ratio in Figures 4a, 4b, and 4c.

DISCUSSION OF CORRELATION

In order to discuss the correlation of the results obtained from the mathematical model to the model data, the speed range will be broken down into two components. The first speed range will be defined to be below design speed and the second will be above design speed. The design speed for hull forms 1 and 2 is approximately equal to a speed-length ratio of .8 and for hull form 3 the design speed-length ratio is about 1.2. It is assumed that the appendage drag below design speed is for the most part dependent on Reynolds number and that the contribution of the Froude dependent resistance becomes a factor slightly below and about design speed.

Figure 4 indicates that the agreement between the mathematical model and the model data below design speed is very good. For example, the average magnitude of this difference at 80 percent design speed is less than 0.2 pounds. We may, therefore, deduce that the mathematical model is valid in this speed range. The deviation from the mean may be caused by a misalignment of such appendages as struts, stabilizer fins, bilge keels, etc., to the flow and will be discussed later in the text. For now, it will be called an induced drag (R_I) that is, in nature, independent of Reynolds number.

The case for the differences between the results from the mathematical model and the model data is similar for the higher speed range. However,

the magnitude is larger, which would tend to confirm the second part of our assumption, i.e., that the Froude number dependent resistance has an effect at the higher speed-values. The shape of the curve through the data is still more evidence indicating the Froude number dependence of this component of the appendage drag.

INTERACTION BETWEEN APPENDAGES AND HULL

If it is assumed that part of the difference between the calculated values and those data deduced from the model resistance tests is due to the previously mentioned induced resistance caused by misalignment to the flow, then the question arises as to what causes the rest of the difference? This may be answered by using some deductive reasoning.

It is a well known phenomenon that an appended model will not necessarily have the same trim characteristics as a bare hull model. It is also known that the trim of a model has an effect on its wave making resistance. Now, it will be recalled that the model data used for the verification of the mathematical model were obtained by subtracting the bare hull model resistance from the appended hull model resistance. Furthermore, since we were able to predict all but 0.2 pounds of the appendage drag up to 80 percent of design speed (this being almost totally dependent on Reynolds number) there is no reason to believe that we do not have the same relative accuracy for predicting Reynolds number dependent drag above the design speed. It appears to be reasonable, therefore, to deduce that the remainder of the difference between the values obtained from the calculation procedure and the model data is caused by the interaction of the appendages on the hull form and that this interaction is a resistance that is Froude number dependent and wave making in nature.

CONCLUSIONS

Summarizing what has been accomplished in the preceding chapters, the following conclusions may be drawn.

1. A mathematical model has been developed for the prediction of the viscous components for appendage drag.

2. The predictions obtained from the mathematical model have been correlated with model appendage resistance data obtained from the results of fourteen ship-model resistance tests and the mathematical model was found to be an effective means of predicting appendage drag.

The differences between the results from the mathematical model and the model data appear to be due to two basic resistance components, i.e., induced drag due to misalignment of an appendage to the flow and a Froude number dependent drag due to the interaction between the appendages and the hull form. These effects will be considered at greater length as this study progresses.

3. A Fortran IV computer program, refer to Appendix I, to be used on the Center's CDC 6700 computer has been developed using the mathematical expressions presented herein. The computer program as presented herein utilizes excessive core space and is presently being modified. The modified version will be available by 1 March 1972. The program also contains an error in the base drag formulation; however, this error is being corrected in the modified version. The present form will provide correct drag values as long as base drag terms are not needed.

RECOMMENDATIONS

A procedure for calculating the vector lift and drag components of the appendages could be developed, and their effect on the change in trim angle correlated to the added appendage drag due to change in underway trim. This could be done by assuming that the forces acting on the appendages are located at the centroid of the appendages; then by taking the sum of the moments about the center of flotation, the change in trim due to the addition of appendages could be calculated. These developments would be very helpful to the designer.

An experimental study should be conducted on a set of carefully selected geosims to verify the scaling technique. This study should also indicate if a correlation allowance for appendages is necessary. Since it may be difficult to conduct some phases of such an experimental program in a towing tank due to the size of some of the larger geosim appendages, the use of a subsonic wind tunnel may be considered as complementing the work done in a towing tank.

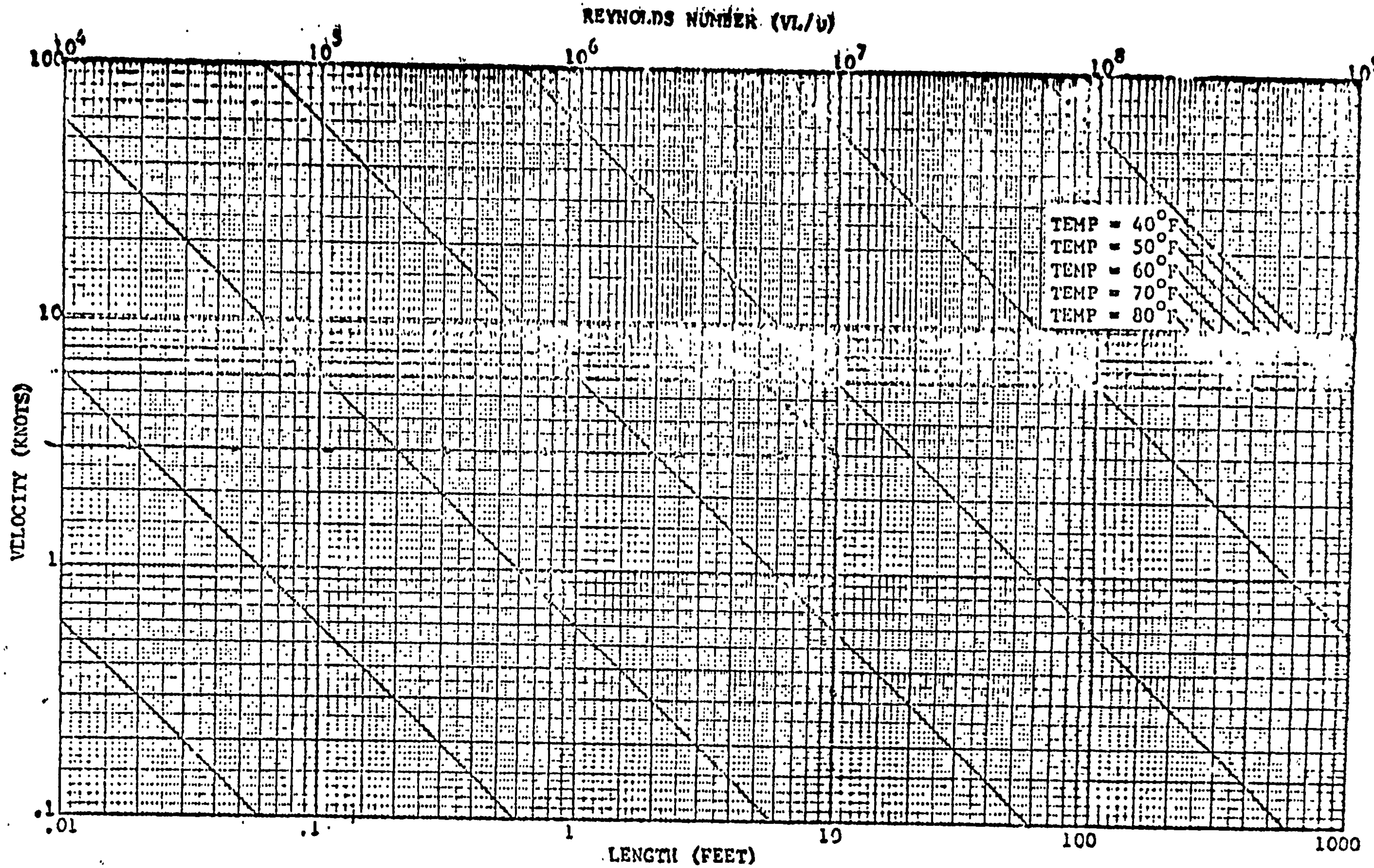

FIGURE 1 - Graphical Representation of the Reynolds Number Formula as a Function of Velocity, Length and Temperature

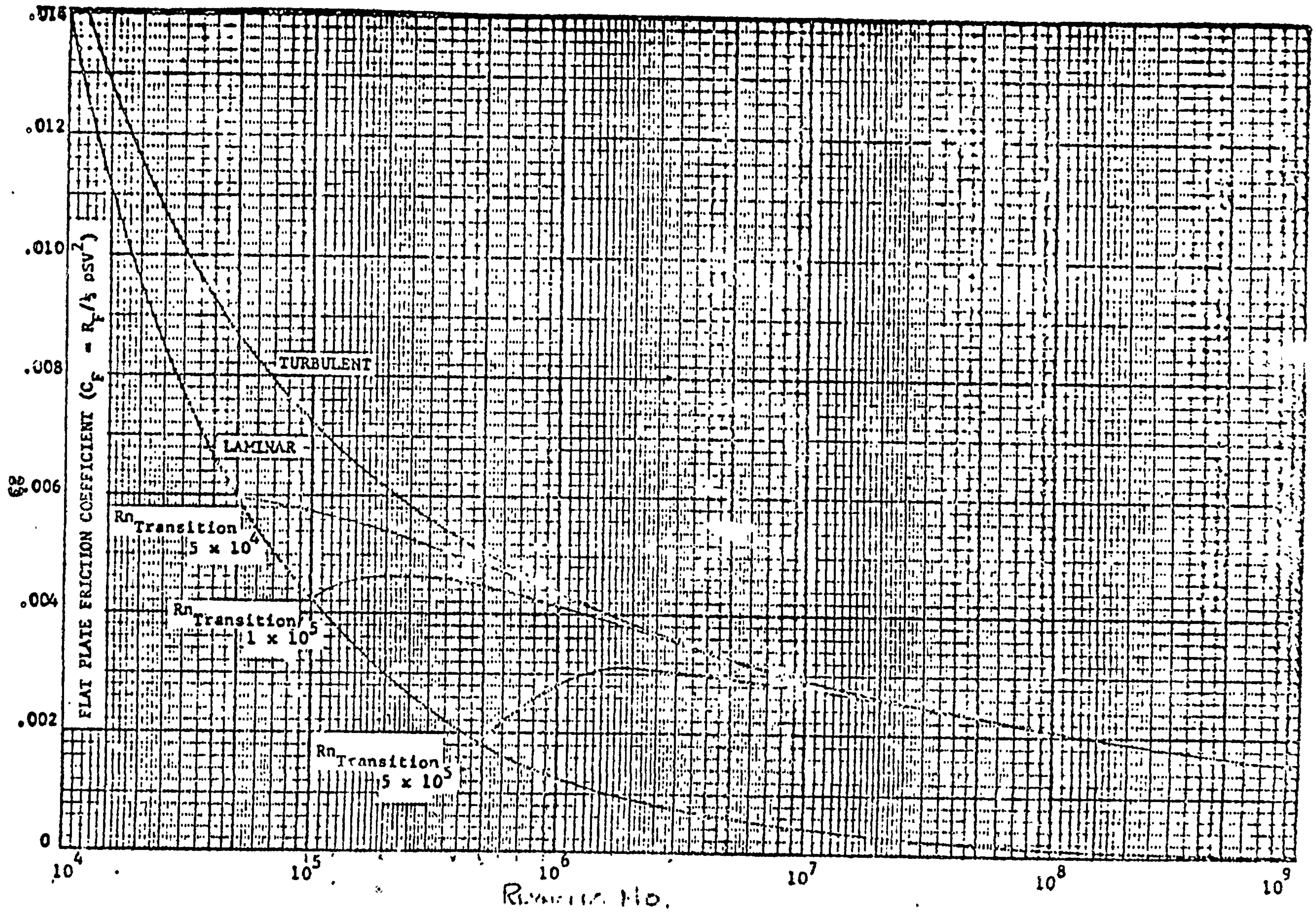

Figure 2 - Curves of Laminar, Transition and Turbulent Flat Plate Friction Coefficient as a Function of Reynolds Number

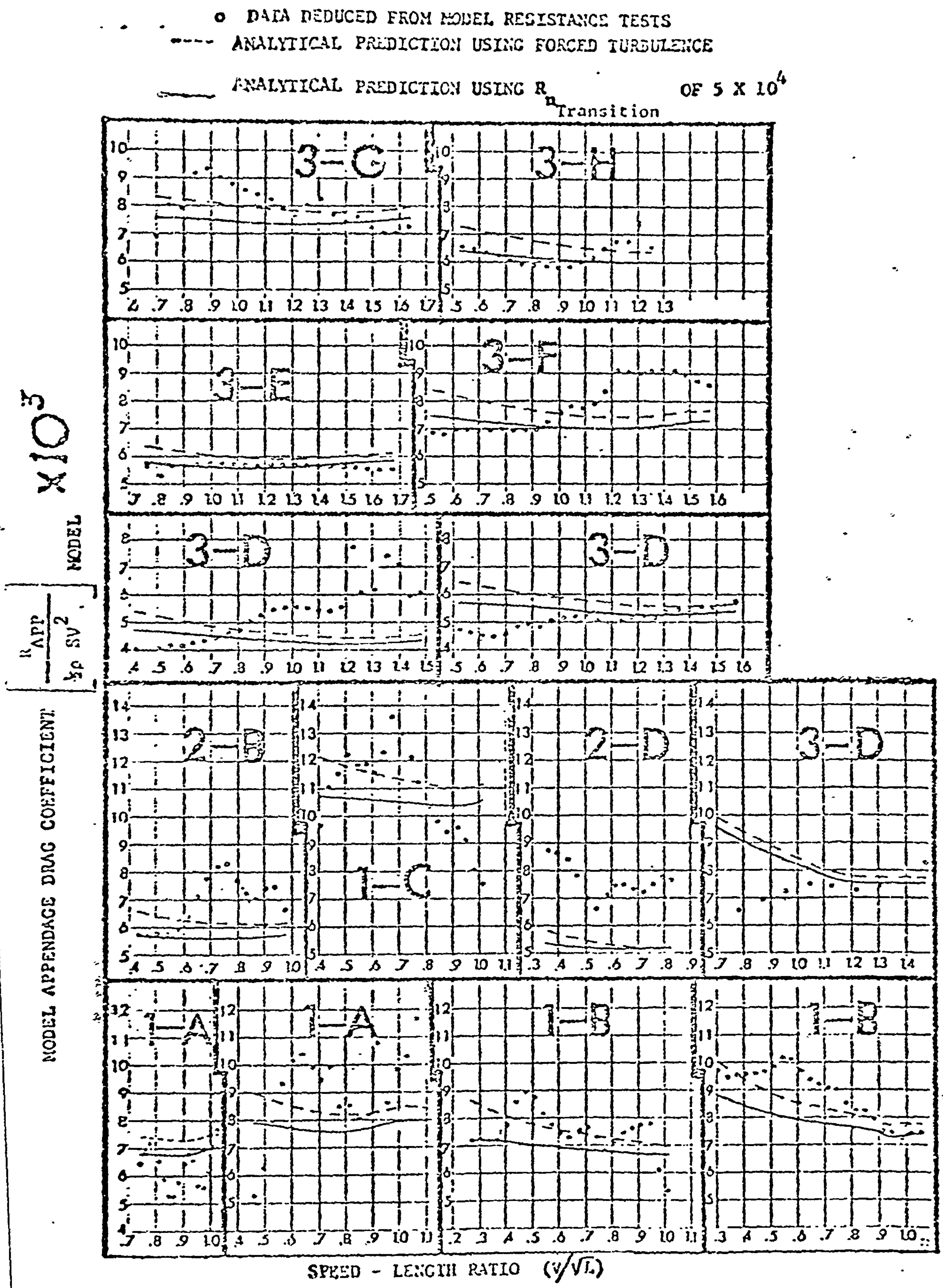

Figure 3 - Comparison of Values of Appendage Drag Obtained from the Mathematical Model with those Deduced from Center Bare Hull and Appended Ship-Model Resistance Tests

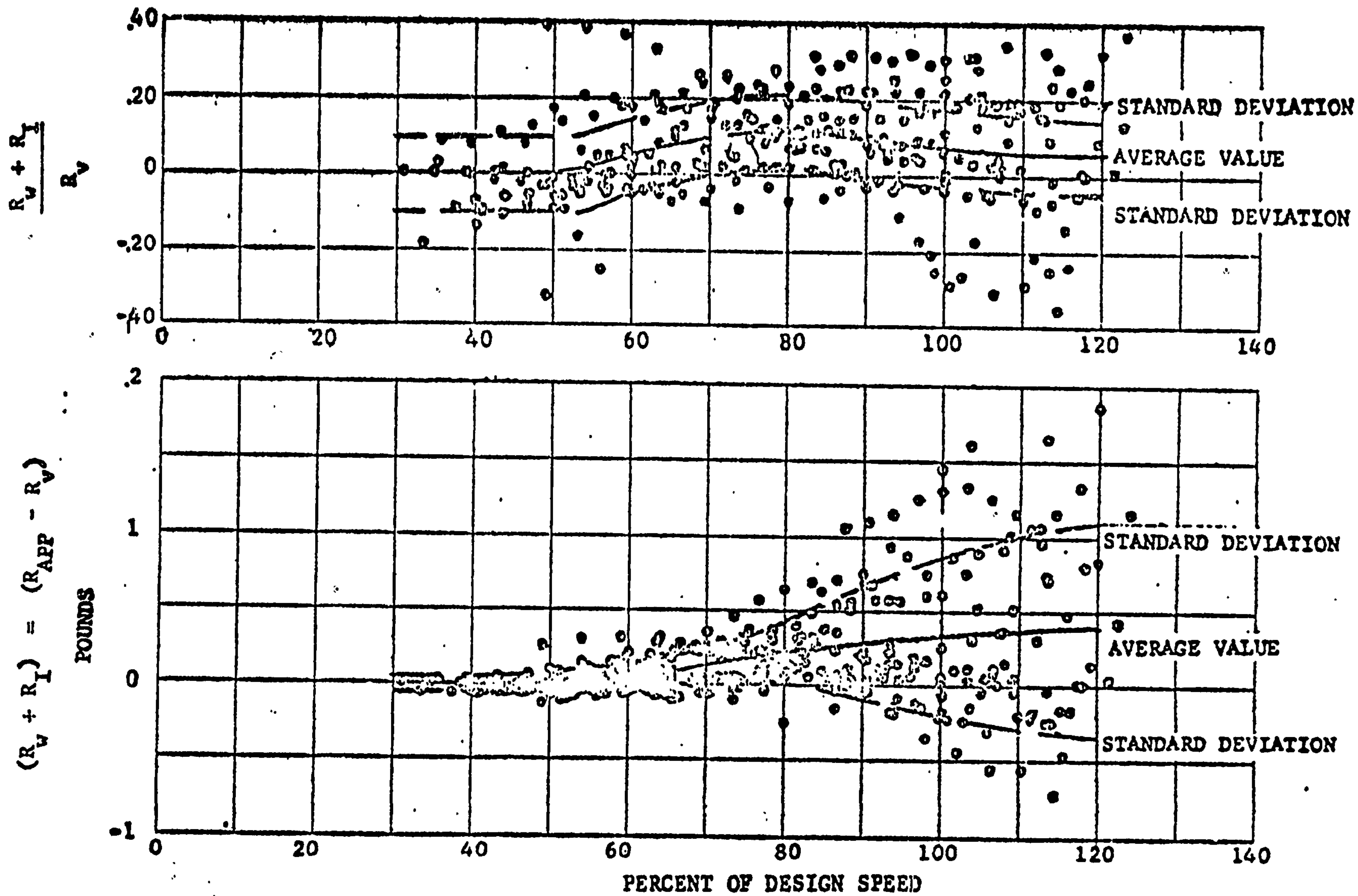

Figure 4 - Model Scale Differences Between Center Tests and the Mathematical Model.

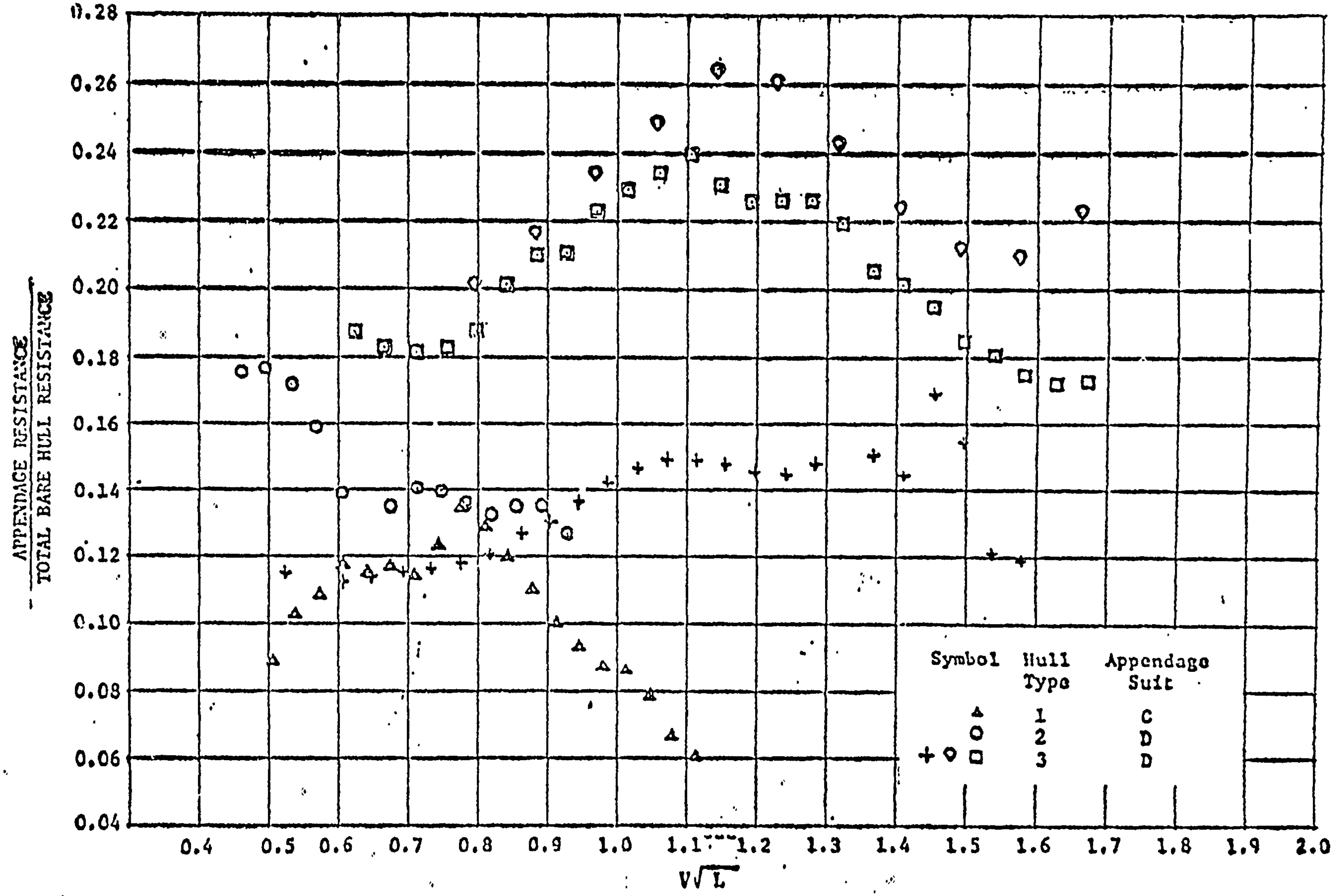

Figure 4a - Comparison of Values of Appendage Drag as a Percentage of Bare Hull Drag Deduced from Center Bare Hull and Appended Ship-Model Resistance Tests

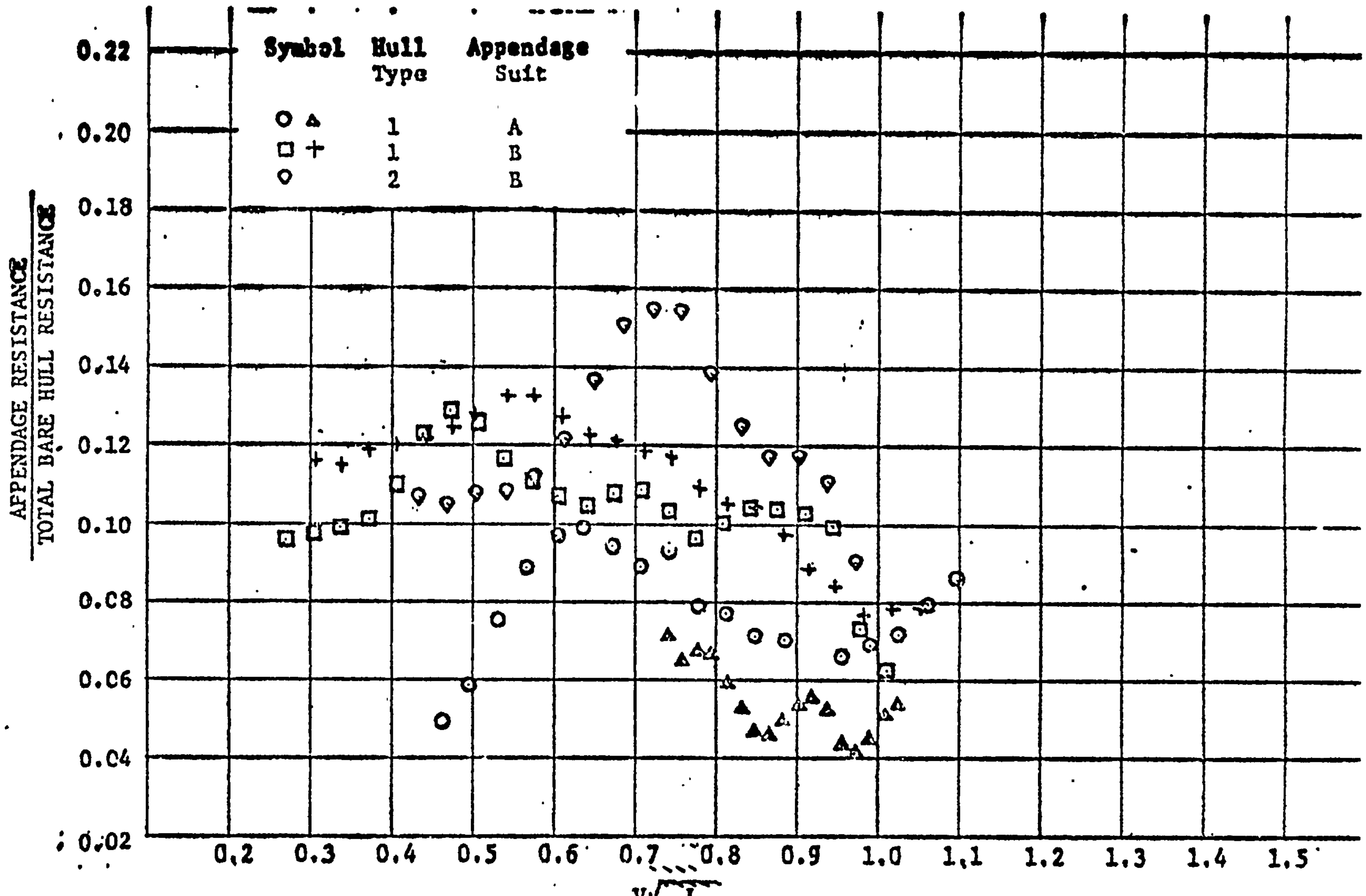

Figure 4b - Comparison of Values of Appendage Drag as a Percentage of Bare Hull Drag Deduced from Center Bare Hull and Appended Ship-Model Resistance Tests

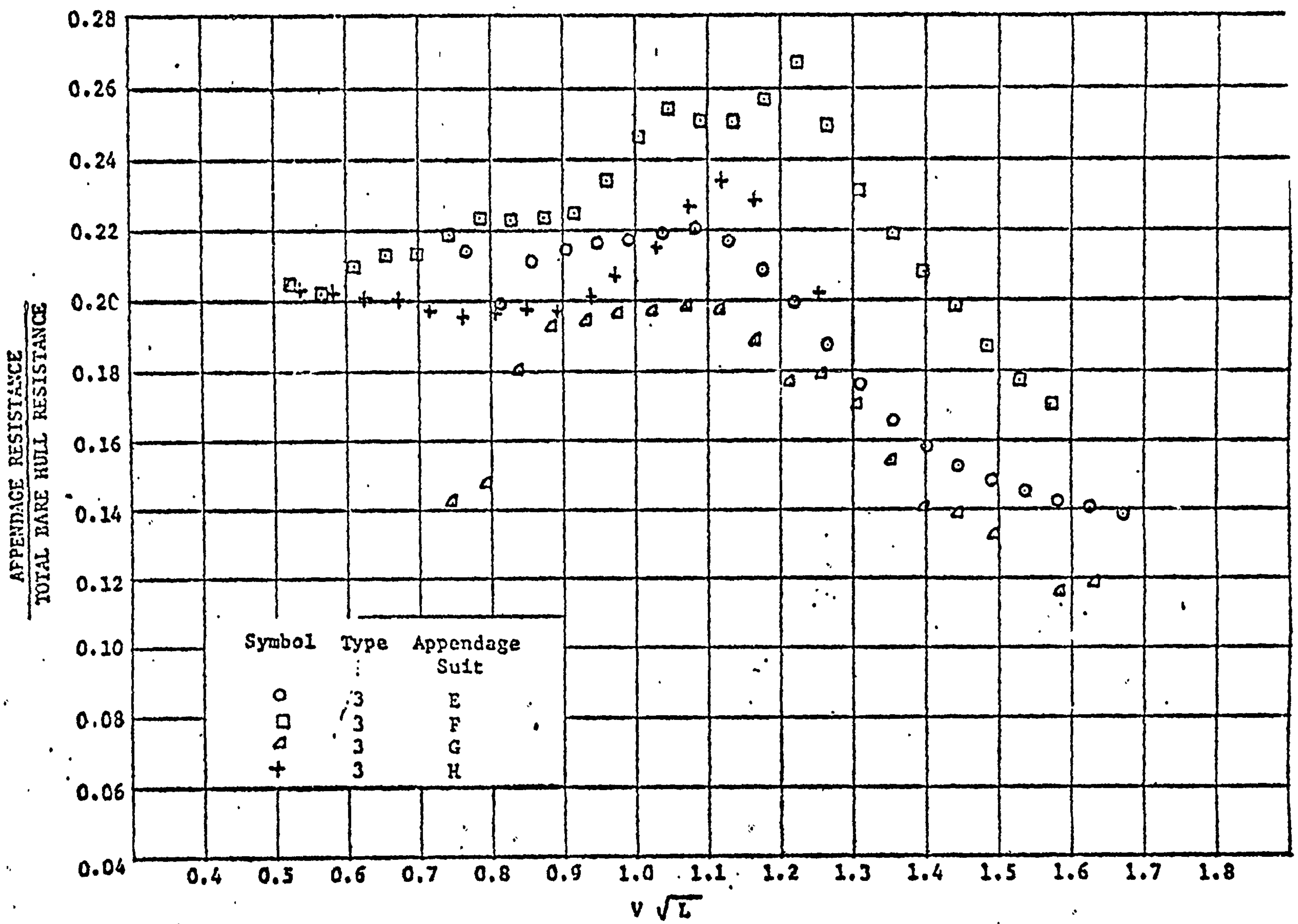

Figure 4c - Comparison of Values of Appendage Drag as a Percentage of Bare Hull Drag Deduced from Center Bare Hull and Appended Ship-Model Resistance Tests

APPENDIX I - LISTING OF COMPUTER PROGRAM

APPEND is a Fortran computer program which may be used to calculate the Reynolds number dependent resistance of the appendages previously mentioned in this text. The program, which has been written for the Center's CDC 6700 computer, will calculate appendage drag for any size appendage, i.e., model-scale or full-scale. APPEND consists of the following subroutines: RUDDER, STRUT, FIN, SHAFT, BOSS, MAIN, BILGE, SKEG, and FRICT, and the function PRESUR. In general, the first eight subroutines are used to calculate the various viscous drag components of the appendage indicated by the title. Subroutines FRICT is used to calculate the friction coefficient (C_F), based on a Reynolds number of transition of 5×10^4. Function PRESUR is used to calculate the basic pressure coefficient described in equation (11).

```
      PROGRAM APPEND(INPUT,OUTPUT)
      COMMON ISPOT,VFW(25),VSFW(25),VRL(25),RHO,XNU,RHOS,XNUS,XLAM
      COMMON/P1/NRUD,SRUD(4),TRUD(4),CRUD(4),DRUD(25),DRUDS(25),DFRUD(25
     1),DFSRUD(25),TRRUD(4),SRRUD(4)
      COMMON/P2/NSTRUT,SSTRUT(16),TSTRUT(16),CSTRUT(16),DSTRUT(25),DSTRU
     1TS(25),DFSTRUT(25),DFSSTRU(25),TOSTRUT(16),SOSTRUT(16)
      COMMON/P3/NFIN,SFIN(4),TFIN(4),CFIN(4),DFIN(25),DFINS(25),DFFIN(25
     1),DFSFIN(25),TOFIN(4),SOFIN(4)
      COMMON/P4/NSHAFT,XLSHAFT(8),RSHAFT(8),ASHAFT(8),DSHAFT(25),DSHAFTS
     1(25),HSHAFT(8),DFSHAFT(25),DFSSHAF(25)
      COMMON/P5/NBOSS,XLBOSS(8),RBOSS(8),ABOSS(8),DBOSS(25),DBOSSS(25),H
     1BOSS(8),DFBOSS(25),DFSBOSS(25)
      COMMON/P6/NMAIN,XLMAIN(4),RMAIN(4),AMAIN(4),RRMAIN(4),DMAIN(25),DM
     1AINS(25),HMAIN(4),DFMAIN(25),DFSMAIN(25)
      COMMON/P7/NBILGE,XLBILGE(4),SBILGE(4),DBILGE(25),DBILGES(25),DFBIL
     1GE(25),DFSBILG(25)
      COMMON/P8/NSKEG,XLSKEG(4),SSKEG(4),DSKEG(25),DSKEGS(25),DFSKEG(25)
     1,DFSSKEG(25)
      DIMENSION VT(25),TITLE(13),CVISAPP(25),CVISAPS(25),DAPP(25),DAPPS(
     125),VM(25),VS(25),VF(25),VSF(25),DFAPP(25),DFSAPP(25),CFPFAPP(25),
     2CFPFAPS(25)
      READ [illegible],NCASE
      PRIN[illegible],NCASE
    5 FORMAT(I5)
C
C     NCASE = NUMBER OF INPUT CASES
C
      DO 680 K=1,NCASE
      PRINT 10
   10 FORMAT(1H1,48X,24H PRINT OUT OF INPUT DATA///)
      READ 15,(TITLE(I),I=1,13)
      PRINT15,(TITLE(I),I=1,13)
   15 FORMAT(13A5)
      READ 20,ISPOT,SM,RHO,XNU,RHOS,XNUS,XLAM,XLSHIP
      PRINT20,ISPOT,SM,RHO,XNU,RHOS,XNUS,XLAM,XLSHIP
C
C     ISPOT=NUMBER OF SPEEDS INPUT
C     SM=APPENDAGE WETTED SURFACE IN SQUARE FEET FOR MODEL
C     RHO=WATER DENSITY FOR APPENDED HULL TEST IN SLUGS/CUBIC FOOT
C     XNU=VISCOSITY OF WATER FOR APPENDED HULL TEST IN(FEET SQ/SEC)X100000
C     XLAM=LENGTH OF SHIP/LENGTH OF MODEL(LINEAR RATIO)
C     XLSHIP=LENGTH OF SHIP IN FEET
C
   20 FORMAT(I5,7F10.5)
C
C     RHOS=WATER DENSITY AT WHICH FULL-SCALE PREDICTION IS TO BE MADE
C          USUALLY TAKEN AT 59 DEG.F. FOR SEA WATER RHOS=1.9905 SLUGS/CUBIC FOOT
C     XNUS=WATER VISCOSITY AT WHICH FULL-SCALE PREDICTION IS TO BE MADE
C          USUALLY TAKEN AT 59 DEG.F. FOR SEA WATER XNUS=1.2817 FEET SQ/SEC
C
      READ 30,NRUD,NSTRUT,NSHAFT,NBOSS,NMAIN,NBILGE,NSKEG,NFIN
      PRINT30,NRUD,NSTRUT,NSHAFT,NBOSS,NMAIN,NBILGE,NSKEG,NFIN
C
C     NXXX=NUMBER OF RUDDERS,STRUTS,ETC.
C
   30 FORMAT(8I5)
      READ 40,(VS(I),VT(I),I=1,ISPOT)
      PRINT40,(VS(I),VT(I),I=1,ISPOT)
C
C     VS(I)=SHIP SPEED IN KNOTS
C     WT(I)=VELOCITY WAKE FRACTION(1-WT)
C
      SMS=SM*XLAM*XLAM
      RTXLAM=SQRT(XLAM)
      RTXLSP=SQRT(XLSHIP)
C
C     SMS=WETTED SURFACE OF SHIP APPENDAGES
C     RTXLAM= SQUARE ROOT OF THE LINEAR RATIO
C     RTXLSP= SQUARE ROOT OF THE SHIP LENGTH.
C
      DO 35 I=1,ISPOT
      VSF(I)=VS(I)*1.6878
      VF(I)=VSF(I)/RTXLAM
      VM(I)=VF(I)/1.6878
      VRL(I)=VS(I)/RTXLSP
      VFW(I)=VF(I)*VT(I)
      VSFW(I)=VSF(I)*VT(I)
      DRUD(I)=0.
      DRUDS(I)=0.
      DFRUD(I)=0.
      DFSRUD(I)=0.
      DSTRUT(I)=0.
      DSTRUTS(I)=0.
      DFSTRUT(I)=0.
      DFSSTRU(I)=0.
      DFIN(I)=0.
      DFINS(I)=0.
      DFFIN(I)=0.
      DFSFIN(I)=0.
      DSHAFT(I)=0.
      DSHAFTS(I)=0.
      DFSHAFT(I)=0.
      DFSSHAF(I)=0.
      DBOSS(I)=0.
      DBOSSS(I)=0.
      DFBOSS(I)=0.
      DFSBOSS(I)=0.
      DMAIN(I)=0.
      DMAINS(I)=0.
      DFMAIN(I)=0.
      DFSMAIN(I)=0.
      DBILGE(I)=0.
      DBILGES(I)=0.
      DFBILGE(I)=0.
      DFSBILG(I)=0.
      DSKEG(I)=0.
      DSKEGS(I)=0.
      DFSKEG(I)=0.
      DFSSKEG(I)=0.
   30 CONTINUE
```

```
C
C     VSF(I)=SHIP SPEED IN FEET PER SECOND
C     VF(I)=MODEL SPEED IN FEET PER SECOND
C     VRL(I)=SPEED LENGTH RATIO
C     VFW(I)=MODEL SPEED CORRECTED FOR WAKE IN FEET PER SECOND
C     VSFW(I)=SHIP SPEED CORRECTED FOR WAKE IN FEET PER SECOND
C
   40 FORMAT(2F10.5)
C
C     READ IN RUDDER PARAMETERS
C
      IF(NRUD) 50,75,50
   50 READ 60,(SRUD(J),TRUD(J),CRUD(J),TBRUD(J),SBRUD(J),J=1,NRUD)
      PRINT60,(SRUD(J),TRUD(J),CRUD(J),TBRUD(J),SBRUD(J),J=1,NRUD)
C
C     SRUD=PLANFORM AREA OF ONE SIDE OF RUDDER IN SQUARE FEET
C     TRUD=THICKNESS IN FEET OF RUDDER
C     CRUD=CHORD LENGTH OF RUDDER IN FEET
C     TBRUD=THICKNESS OF BASE(TRAILING EDGE) OF RUDDER IN FEET
C     SBRUD=AREA OF TRAILING EDGE RUDDER IN SQUARE FEET
C
   60 FORMAT(5F10.5)
   75 IF(NSTRUT) 80,105,80
   80 READ 60,(SSTRUT(J),TSTRUT(J),CSTRUT(J),TBSTRUT(J),SBSTRUT(J),J=1,N
     1STRUT)
      PRINT60,(SSTRUT(J),TSTRUT(J),CSTRUT(J),TBSTRUT(J),SBSTRUT(J),J=1,N
     1STRUT)
C
C     SSTRUT=PLANFORM AREA OF ONE SIDE OF STRUT IN SQUARE FEET
C     TSTRUT=THICKNESS OF STRUT IN FEET
C     CSTRUT=CHORD LENGTH OF STRUT IN FEET
C     TBSTRUT=THICKNESS OF BASE (TRAILING EDGE) OF STRUT IN FEET
C     SBSTRUT=AREA OF TRAILING EDGE IN SQUARE FEET
C
C     READ IN STABLIZER FIN PARAMETERS
C
  105 IF(NFIN) 110,135,110
  110 READ 60,(SFIN(J),TFIN(J),CFIN(J),TBFIN(J),SBFIN(J),J=1,NFIN)
      PRINT60,(SFIN(J),TFIN(J),CFIN(J),TBFIN(J),SBFIN(J),J=1,NFIN)
C
C     SFIN=PLANFORM AREA OF ONE SIDE OF FIN IN SQUARE FEET
C     TFIN=THICKNESS OF FIN IN FEET
C     CFIN=CHORD LENGTH OF BASE (TRAILING EDGE) OF FIN IN FEET
C     SBFIN=AREA OF TRAILING EDGE IN SQUARE FEET
C
C     READ IN MAIN AND INTERMEDIATE SHAFT PARAMETERS
C
  135 IF(NSHAFT) 140,165,140
  140 READ 65,(XLSHAFT(J),RSHAFT(J),ASHAFT(J),HSHAFT(J),J=1,NSHAFT)
      PRINT65,(XLSHAFT(J),RSHAFT(J),ASHAFT(J),HSHAFT(J),J=1,NSHAFT)
   65 FORMAT(4F10.5)
C
C     XLSHAFT=SHAFT LENGTH IN FEET
C     RSHAFT=SHAFT DIAMETER IN FEET
C     ASHAFT=ANGLE OF FLOW(ANGLE BETWEEN SHAFT ABD HULL IN DEGREES
C     HSHAFT=DISTANCE BELOW WL OF SHAFT CL IN FEET
C
C     READ IN STRUT BARREL(INTERMEDIATE ONLY) AND STERNTUBE BOSSING PARAMETER
C
  165 IF(NBOSS) 170,195,170
  170 READ 65,(XLBOSS(J),RBOSS(J),ABOSS(J),HBOSS(J),J=1,NBOSS)
      PRINT65,(XLBOSS(J),RBOSS(J),ABOSS(J),HBOSS(J),J=1,NBOSS)
C
C     XLBOSS=LENGTH IN FEET
C     RBOSS=DIAMETER IN FEET
C     ABOSS=ANGLE OF FLOW IN DEGREES
C     HBOSS=DISTANCE BELOW WL OF BOSS CL IN FEET
C
C     READ IN PARAMETERS FOR THE MAIN STRUT BARREL(INCLUDES DUMMY HUB AND FAI
C
  195 IF(NMAIN) 200,225,200
  200 READ 215,(XLMAIN(J),RMAIN(J),AMAIN(J),HMAIN(J),RBMAIN(J),J=1,NMAIN
     1)
      PRINT215,(XLMAIN(J),RMAIN(J),AMAIN(J),HMAIN(J),RBMAIN(J),J=1,NMAIN
     1)
C
C     XLMAIN=LENGTH IN FEET
C     RMAIN=DIAMETER IN FEET
C     RBMAIN=DIAMETER OF BASE IN FEET(BASE IS FAIRWATER TIP)
C     AMAIN=ANGLE OF FLOW IN DEGREES
C     HMAIN=DISTANCE BELOW WL OF MAIN IN FEET
C
  215 FORMAT(5F10.5)
C
C     READ IN BILGE KEEL PARAMETERS
C
  225 IF(NBILGE) 230,255,230
  230 READ 40,(XLBILGE(J),SBILGE(J),J=1,NBILGE)
      PRINT40,(XLBILGE(J),SBILGE(J),J=1,NBILGE)
C
C     XLBILGE=LENGTH IN FEET
C     SBILGE=AREA IN SQUARE FEET OF BILGE KEEL LESS THE AREA ON THE
C            HULL COVERED UP BY THE BILGE KEEL IN SQUARE FEET
C
C     READ IN SKEG PARAMETERS
C
  255 IF(NSKEG) 260,285,260
  260 READ 40,(XLSKEG(J),SSKEG(J),J=1,NSKEG)
      PRINT40,(XLSKEG(J),SSKEG(J),J=1,NSKEG)
C
C     XLSKEG=LENGTH IN FEET
C     SSKEG=AREA IN SQUARE FEET OF SKEG LESS THE AREA ON THE HULL
C            COVERED UP BY THE SKEG
C
      IF(ISPOT.GT.25) GO TO 670
C
C     CALCULATION OF THE REYNOLDS DEPENDENT COMPONENTS OF RUDDER DRAG
C
  285 IF(NRUD) 290,315,290
  290 CALL RUDDER
```

```
C
C     CALCULATION OF REYNOLDS   DEPENDENT COMPONENTS OF STRUT DRAG
C
  315 IF(NSTRUT) 320,345,320
  320 CALL STRUT
C
C     CALCULATION OF REYNOLDS DEPENNDENT COMPONENTS OF STABILIZERS FIN DRAG
C
  345 IF(NFIN) 350,375,350
  350 CALL FIN
C
C     CALCULATION OF REYNOLDS DEPENDENT COMPONENTS OF SHAFTING DRAG
C
  375 IF(NSHAFT) 380,405,380
  380 CALL SHAFT
C
C     CALCULATION OF REYNOLDS DEPENDENT COMPONENTS OF STERNTURE BOSSINGS
C     AND INTERMEDIATE STRUT BARRELS
C
  405 IF(NBOSS) 410,435,410
  410 CALL BOSS
C
C     CALCULATION OF REYNOLDS DEPENDENT COMPONENTS OF MAIN STRUT BARREL
C     DRAG-THE MAIN STRUT BARREL INCLUDES THE DUMMY HUB(PROPELLER HUB
C     WITHOUT BLADES) AND THE FAIRWATER.
C
  435 IF(NMAIN) 440,465,440
  440 CALL MAIN
C
C     CALCULATION OF BILGE KEEL DRAG
C
  465 IF(NBILGE) 470,495,470
  470 CALL BILGE
C
C     CALCULATION OF SKEG DRAG
C
  495 IF(NSKEG) 500,525,500
  500 CALL SKEG
  525 DO 530 I=1,ISPOT
      DAPP(I)=DRUD(I)+DSTRUT(I)+DFIN(I)+DSHAFT(I)+DBOSS(I)+DMAIN(I)+DBIL
     1GE(I)+DSKEG(I)
      DAPPS(I)=DRUDS(I)+DSTRUTS(I)+DFINS(I)+DSHAFTS(I)+DBOSSS(I)+DMAINS(
     1I)+DBILGES(I)+DSKEGS(I)
      CVISAPP(I)=DAPP(I)/((RHO/2.)*VF(I)*VF(I)*SH)
      CVISAPS(I)=DAPPS(I)/((RHOS/2.)*VSF(I)*VSF(I)*SHS)
  530 CONTINUE
      PRINT 540
  540 FORMAT(87H1 CALCULATED REYNOLDS DEPENDENT RESISTANCE COMPONENTS FO
     1R MODEL SCALE APPENDAGES IN LBS/)
      PRINT 545
  545 FORMAT(117H THE APPENDAGE REYNOLDS DRAG COEFFICIENT=REYNOLDS DRAG(
     1(APP.)/((DENSITY/2.)*(VEL).*(VEL.)*(APPENDAGE WETTED SURFACE))//)
      PRINT 550
  550 FORMAT(1H0,10H  VM-KNOTS,4X,4H VRL,5X,7H RUDDER,3X,6H STRUT,5X,4H
     1FIN,5X,6H SHAFT,4X,5H BOSS,5X,5H MAIN,5X,6H BILGE,4X,5H SKEG,5X,6H
     2 TOTAL,4X,12H COEFFICIENT//)
      DO 570 I=1,ISPOT
      PRINT 560,VM(I),VRL(I),DRUD(I),DSTRUT(I),DFIN(I),DSHAFT(I),DBOSS(I
     1),DMAIN(I),DBILGE(I),DSKEG(I),DAPP(I),CVISAPP(I)
  560 FORMAT(1H ,11F10.3,1P1E15.4)
  570 CONTINUE
      PRINT 580
  580 FORMAT(86H1 CALCULATED REYNOLDS DEPENDENT RESISTANCE COMPONENTS FO
     1R SHIP SCALE APPENDAGES-IN LBS/)
      PRINT 545
      PRINT 555
      DO 600 I=1,ISPOT
      PRINT 590,VS(I),VRL(I),DRUDS(I),DSTRUTS(I),DFINS(I),DSHAFTS(I),DBO
     1SSS(I),DMAINS(I),DBILGES(I),DSKEGS(I),DAPPS(I),CVISAPS(I)
  590 FORMAT(1H ,2F7.3,1P10E12.4)
  600 CONTINUE
  555 FORMAT(1H0,9H VS-KNOTS,5H  VRL,3X,7H RUDDER,5X,6H STRUT,6X,4H FIN,
     18X,6H SHAFT,6X,5H BOSS,7X,5H MAIN,7X,6H BILGE,6X,5H SKEG,7X,6H TOT
     2AL,5X,12H COEFFICIENT//)
      DO 610 I=1,ISPOT
      DFAPP(I)=DFRUD(I)+DFSTRUT(I)+DFFIN(I)+DFSHAFT(I)+DFBOSS(I)+DFMAIN(
     1I)+DFBILGE(I)+DFSKEG(I)
      DFSAPP(I)=DFSRUD(I)+DFSSTRU(I)+DFSFIN(I)+DFSSHAF(I)+DFSBOSS(I)+DFS
     1MAIN(I)+DFSBILG(I)+DFSSKEG(I)
      CFPFAPP(I)=DFAPP(I)/((RHO/2.)*VF(I)*VF(I)*SH)
      CFPFAPS(I)=DFSAPP(I)/((RHO/2.)*VSF(I)*VSF(I)*SHS)
  610 CONTINUE
      PRINT 620
  620 FORMAT(120H1 CALCULATED FLAT PLATE FRICTIONAL RESISTANCE COMPONENT
     1FOR MODEL SCALE APPENDAGES BASED ON LOCAL REYNOLDS NUMBER-IN LBS/)
      PRINT 630
  630 FORMAT(119H THE APPENDAGE FLAT PLATE FRICTION COEFFICIENT=FRICT. D
     1RAG(APP)/((DENSITY/2.)*(VEL.)*(VEL.)*(APPENDAGE WETTED SURFACE))//
     2)
      PRINT 550
      DO 650 I=1,ISPOT
      PRINT 560,VM(I),VRL(I),DFRUD(I),DFSTRUT(I),DFFIN(I),DFSHAFT(I),DFB
     1OSS(I),DFMAIN(I),DFBILGE(I),DFSKEG(I),DFAPP(I),CFPFAPP(I)
  650 CONTINUE
      PRINT 660
  660 FORMAT(118H1 CALCULATED FLAT PLATE FRICTIONAL RESISTANCE COMPONENT
     1FOR SHIP SCALE APPENDAGES BASED ON LOCAL REYNOLDS NUMBER-IN LBS/)
      PRINT 630
      PRINT 555
      DO 665 I=1,ISPOT
      PRINT 590,VS(I),VRL(I),DFSRUD(I),DFSSTRU(I),DFSFIN(I),DFSSHAF(I),D
     1FSBOSS(I),DFSMAIN(I),DFSBILG(I),DFSSKEG(I),DFSAPP(I),CFPFAPS(I)
  665 CONTINUE
      GO TO 680
  670 PRINT 675
  675 FORMAT(1H0,27X,*NUMBER OF SPOTS GREATER THAN 25. REDUCE NUMBER OF
     1SPEEDS AND RERUN*)
  680 CONTINUE
      STOP
      END
```

```
      SUBROUTINE RUDDER
      COMMON ISPOT,VFW(25),VSFW(25),VRL(25),RHO,XNU,RHOS,XNUS,XLAM
      COMMON/R1/NRUD,SRUD(4),TRUD(4),CRUD(4),DRUD(25),DRUDS(25),DFRUD(25
     1),DFSRUD(25),TBRUD(4),SBRUD(4)
      DO 1140 J=1,NRUD
      PRINT 1100,J
 1100 FORMAT(44H1 MODEL AND SHIP SCALE RESISTANCE FOR RUDDER ,I2/)
      PRINT 1110
 1110 FORMAT(1H0,7X,4H VRL,9X,9H REYNOLDS,6X,11H FLAT PLATE,6X,8H VEL AU
     1G,7X,9H PRESSURE,5X,10H INTERSECT,6X,5H BASE,10X,6H TOTAL//)
      DO 1140 I=1,ISPOT
C
C     CALCULATION OF THICKNESS-CHORD RATIOS AND FULL-SCALE PARAMETERS
C
      TOC=TRUD(J)/CRUD(J)
      TOC2=TOC*TOC
      TOC4=TOC2*TOC2
      CRUDS=CRUD(J)*XLAM
      TRUD2=TRUD(J)*TRUD(J)
      TRUDS2=TRUD2*XLAM*XLAM
      SRUDS=SRUD(J)*XLAM*XLAM
      IF(TBRUD(J).LE.0.) GO TO 1105
      CLOTB=CRUD(J)/TBRUD(J)
      SBRUDS=SBRUD(J)*XLAM*XLAM
 1105 CONTINUE
C
C     FLAT PLATE FRICTION COEFFICIENT BASED ON LOCAL REYNOLDS NUMBER
C
      CALL FRICT(CFRUD,REY,VFW(I),CRUD(J),XNU)
      CALL FRICT(CFSRUD,REYS,VSFW(I),CRUDS,XNUS)
C
C     CONSTANTS TO CONVERT DRAG COEFFICIENTS TO RESISTANCE IN POUNDS
C     XM=MODEL CONSTANT
C     XS=SHIP CONSTANT
C
      XM=.5*RHO*SRUD(J)*VFW(I)*VFW(I)
      XS=.5*RHOS*SRUDS*VSFW(I)*VSFW(I)
C
C     CALCULATION OF DRAG COMPONENTS FOR A SYMETRICAL FOIL SECTION
C
      CALL FOILSEC(XM,XS,CFRUD,CFSRUD,TOC,TOC2,TOC4,SRUD(J),
     1SRUDS,TRUD2,TRUDS2,SBRUD(J),SBRUDS,CLOTB,RF,RFS,RFVA,RFVAS,RP,RPS,
     2RINT,RINTS,RB,RBS)
C
C     TOTAL OF COMPONENT DRAGS
C
      D=RF+RFVA+RP+RINT+RB
      DS=RFS+RFVAS+RPS+RINTS+RBS
C
C     SUMMATION OF REYNOLDS DEPENDENT RESISTANCES TO OBTAIN TOTAL AMOUNT
C     FOR ALL RUDDERS COMBINED PRINTED OUT FROM MAIN PROGRAM
C
      DRUD(I)=DRUD(I)+D
      DRUDS(I)=DRUDS(I)+DS
      DFRUD(I)=DFRUD(I)+RF
      DFSRUD(I)=DFSRUD(I)+RFS
C
C     PRINT OUT OF RESISTANCE INFORMATION FOR MODEL AND SHIP OF EACH
C     RUDDER WITH ITS REYNOLDS DEPENDENT RESISTANCE COMPONENTS
C
      PRINT 1120,VRL(I),REY,RF,RFVA,RP,RINT,RB,D
 1120 FORMAT(1P8F15.3,6H MODEL)
      PRINT 1130,VRL(I),REYS,RFS,RFVAS,RPS,RINTS,RBS,DS
 1130 FORMAT(1P8F15.3,5H SHIP/)
 1140 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE STRUT
      COMMON ISPOT,VFW(25),VSFW(25),VPL(25),RHO,XNU,RHOS,XNUS,XLAM
      COMMON/B2/NSTRUT,SSTRUT(16),TSTRUT(16),CSTRUT(16),DSTRUT(25),DSTRU
     1TS(25),DFSTRUT(25),DFSSTRU(25),TBSTRUT(16),SBSTRUT(16)
      DO 2140 J=1,NSTRUT
      PRINT 2100,J
 2100 FORMAT(43H1 SHIP AND MODEL SCALE RESISTANCE FOR STRUT ,I2/)
      PRINT 2110
 2110 FORMAT(1H0,7X,4H VPL,9X,9H REYNOLDS,6X,11H FLAT PLATE,4X,8H VEL AU
     1G,7X,9H PRESSURF,6X,10H INTERSECT,6X,5H BASE,10X,6H TOTAL//)
      DO 2140 I=1, SPOT
C
C     CALCULATION OF THICKNESS-CHORD RATIOS AND FULL SCALE PARAMETERS
C
      TOC=TSTRUT(J)/CSTRUT(J)
      TOC2=TOC*TOC
      TOC4=TOC2*TOC2
      CSTRUTS=CSTRUT(J)*XLAM
      TSTRUT2=TSTRUT(J)*TSTRUT(J)
      TSTRUS2=TSTRUT2*XLAM*XLAM
      SSTRUS=SSTRUT(J)*XLAM*XLAM
      IF(TBSTRUT(J).LE.0.) GO TO 2105
      CLOTB=CSTRUT(J)/TBSTRUT(J)
      SBSTRUS=SBSTRUT(J)*XLAM*XLAM
 2105 CONTINUE
C
C     FLAT PLATE FRICTION COEFFICIENT BASED ON LOCAL REYNOLDS NUMBER
C
      CALL FRICT(CFSTRUT,REY,VFW(I),CSTRUT(J),XNU)
      CALL FRICT(CFSSTRU,REYS,VSFW(I),CSTRUTS,XNUS)
C
C     CONSTANTS TO CONVERT DRAG COEFFICIENTS TO RESISTANCE IN POUNDS
C
C     XM=MODEL CONSTANT
C     XS=SHIP CONSTANT
C
      XM=.5*RHO*SSTRUT(J)*VFW(I)*VFW(I)
      XS=.5*RHOS*SSTRUS*VSFW(I)*VSFW(I)
C
C     CALCULATION OF DRAG COMPONENTS FOR A SYMETRICAL FOIL SECTION
C
      CALL FOILSEC(XM,XS,CFSTRUT,CFSSTRU,TOC,TOC2,TOC4,SSTRUT
     1(J),SSTRUS,TSTRUT2,TSTRUS2,SBSTRUT(J),SBSTRUS,CLOTB,RF,RFS,RFVA,RF
     2VAS,RP,RPS,RINT,RINTS,RB,RBS)
C
C     RINT AND RINTS MUST BE MULTIPLIED BY 2 IN THE CASE FOR STRUTS
C     SINCE THE STRUT NOT ONLY INTERSECTS THE HULL, BUT IT ALSO MAKES
C     AN INTERSECTION WITH THE STRUT BARRELS
C
      RINT=2.*RINT
      RINTS=2.*RINTS
C
C     TOTAL OF COMPONENT DRAGS
C
      D=RF+RFVA+RP+RINT+RB
      DS=RFS+RFVAS+RPS+RINTS+RBS
C
C     SUMMATION OF REYNOLDS DEPENDENT RESISTANCES TO OBTAIN TOTAL AMOUNT
C     FOR ALL STRUTS COMBINED PRINTED OUT FROM MAIN PROGRAM
C
      DSTRUT(I)=DSTRUT(I)+D
      DSTRUTS(I)=DSTRUTS(I)+DS
      DFSTRUT(I)=DFSTRUT(I)+RF
      DFSSTRU(I)=DFSSTRU(I)+RFS
C
C     PRINT OUT OF RESISTANCE INFORMATION FOR MODEL AND SHIP OF EACH
C     STRUT WITH ITS REYNOLDS DEPENDENT RESISTANCE COMPONENTS
C
      PRINT 2120,VPL(I),REY,RF,RFVA,RP,RINT,RB,D
 2120 FORMAT(1P8E15.3,6H MODEL)
      PRINT 2130,VPL(I),REYS,RFS,RFVAS,RPS,RINTS,RBS,DS
 2130 FORMAT(1P8E15.3,5H SHIP/)
 2140 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FIN
      COMMON ISPOT,VFW(25),VSFW(25),VRL(25),RHO,XNU,RHOS,XNUS,XLAM
      COMMON/R3/NFIN,SFIN(4),TFIN(4),CFIN(4),DFIN(25),DFINS(25),DFFIN(25
     1),DFSFIN(25),TRFIN(4),SRFIN(4)
      DO 3140 J=1,NFIN
      PRINT 3100,J
 3100 FORMAT(41H1 MODEL AND SHIP SCALE RESISTANCE FOR FIN ,I2/)
      PRINT 3110
 3110 FORMAT(1H0,7X,4H VRL,9X,9H REYNOLDS,6X,11H FLAT PLATE,4X,8H VFL AU
     1G,7X,9H PRESSURE,6X,10H INTERSECT,6X,5H BASE,10X,6H TOTAL//)
      DO 3140 I=1,ISPOT
C
C     CLACULATION OF THICKNESS-CHORD RATIOS AND FULL-SCALE PARAMETERS
C
      TOC=TFIN(J)/CFIN(J)
      TOC2=TOC*TOC
      TOC4=TOC2*TOC2
      CFINS=CFIN(J)*XLAM
      TFIN2=TFIN(J)*TFIN(J)
      TFINS2=TFIN2*XLAM*XLAM
      SFINS=SFIN(J)*XLAM*XLAM
      IF(TRFIN(J).LE.0.) GO TO.3105
      CLORB=CFIN(J)/TRFIN(J)
      SRFINS=SRFIN(J)*XLAM*XLAM
 3105 CONTINUE
C
C     FLAT PLATE FRICTION COEFFICIENT BASED ON LOCAL REYNOLDS NUMBER
C
      CALL FRICT(CFFIN,REY,VFW(I),CFIN(J),XNU)
      CALL FRICT(CFSFIN,REYS,VSFW(I),CFINS,XNUS)
C
C     CONSTANTS TO CONVERT DRAG COEFFICIENTS TO RESISTANCE IN POUNDS
C     XM=MODEL CONSTANT
C     XS=SHIP CONSTANT
C
      XM=.5*RHO*SFIN(J)*VFW(I)*VFW(I)
      XS=.5*RHOS*SFINS*VSFW(I)*VSFW(I)
C
C     CALCULATION OF DRAG COMPONENTS FOR A SYMETRICAL FOIL SECTION
C
      CALL FOILSEC(XM,XS,CFFIN,CFSFIN,TOC,TOC2,TOC4,SFIN(J),
     1SFINS,TFIN2,TFINS2,SRFIN(J),SRFINS,CLORB,RF,RFS,RFVA,RFVAS,RP,RPS,
     2RINT,RINTS,RB,RBS)
C
C     TOTAL OF COMPONENT DRAGS
C
      D=RF+RFVA+RP+RINT+RB
      DS=RFS+RFVAS+RPS+RINTS+RBS
C
C     SUMMATION OF REYNOLDS DEPENDENT RESISTANCES TO OBTAIN TOTAL AMOUNT
C     FOR ALL STRUTS COMBINED PRINTED OUT FROM MAIN PROGRAM
C
      DFIN(I)=DFIN(I)+D
      DFINS(I)=DFINS(I)+DS
      DFFIN(I)=DFFIN(I)+RF
      DFSFIN(I)=DFSFIN(I)+RFS
C
C     PRINT OUT OF RESISTANCE INFORMATION FOR MODEL AND SHIP OF EACH
C     FIN WITH ITS REYNOLDS DEPENDENT RESISTANCE COMPONENTS
C
      PRINT 3120,VRL(I),REY,RF,RFVA,RP,RINT,RB,D
 3120 FORMAT(1P8E15.3,6H MODEL)
      PRINT 3130,VRL(I),REYS,RFS,RFVAS,RPS,RINTS,RBS,DS
 3130 FORMAT(1P8E15.3,5H SHIP/)
 3140 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SHAFT
      COMMON ISPOT,VFW(25),VSFW(25),VAL(25),RHO,XNU,RHOS,XNUS,XLAM
      COMMON/B4/NSHAFT,XLSHAFT(8),RSHAFT(8),ASHAFT(8),DSHAFT(25),DSHAFTS
     1(25),HSHAFT(8),DFSHAFT(25),DFSSHAF(25)
      DO 4140 J=1,NSHAFT
      PRINT 4100,J
 4100 FORMAT(43H1 MODEL AND SHIP SCALE RESISTANCE FOR SHAFT ,I2/)
      PRINT 4110
 4110 FORMAT(1H0,7X,4H VAL,9X,9H REYNOLDS,6X,9H FRICTION,6X,9H PRESSURE,
     86X,AH TOTAL//)
      DO 4140 I=1,ISPOT
C
C     CALCULATION OF RATIOS,CONSTANTS AND FULL-SCALE DIMENSIONS
C
      RAD=ASHAFT(J)*0.017453
      RADSIN=SIN(RAD)
      RAD3=RADSIN*RADSIN*RADSIN
      XLSSHAF=XLSHAFT(J)*XLAM
      RSSHAFT=RSHAFT(J)*XLAM
      HSSHAFT=HSHAFT(J)*XLAM
C
C     FLAT PLATE FRICTION COEFFICIENT BASED ON LOCAL REYNOLDS NUMBER
C
      CALL FRICT(CFSHAFT,REY,VFW(I),XLSHAFT(J),XNU)
      CALL FRICT(CFSSHAF,REYS,VSFW(I),XLSSHAF,XNUS)
C
C     CONSTANTS TO CONVERT DRAG COEFFICIENTS TO RESISTANCE IN POUNDS
C     XM=MODEL CONSTANT
C     XS=SHIP CONSTANT
C
      XM=.5*RHO*XLSHAFT(J)*RSHAFT(J)*VFW(I)*VFW(I)
      XS=.5*RHOS*XLSSHAF*RSSHAFT*VSFW(I)*VSFW(I)
C
C     CALCULATION OF THE BASIC PRESSURE DRAG COEFFICIENT
C
      CDBASH=PRESUR(RHO,VFW(I),RSHAFT(J),HSHAFT(J),XNU)
      CDBASS=PRESUR(RHOS,VSFW(I),RSSHAFT,HSSHAFT,XNUS)
C
C     CALCULATION OF PRESSURE DRAG CORRECTED FOR CROSSFLOW
C
      RPRES=XM*CDBASH*RAD3
      RSPRES=XS*CDBASS*RAD3
C
C     FRICTIONAL RESISTANCE
C
      RF=XM*3.14159*CFSHAFT
      RFS=XS*3.14159*CFSSHAF
C
C     TOTAL OF COMPONENT DRAGS
C
      D=RPRES+RF
      DS=RSPRES+RFS
C
C     SUMMATION OF REYNOLDS DEPENDENT RESISTANCE TO OBTAIN TOTAL AMOUNT
C     FOR ALL SHAFTS COMBINED-PRINTED OUT FROM MAIN PROGRAM
C
      DSHAFT(I)=DSHAFT(I)+D
      DSHAFTS(I)=DSHAFTS(I)+DS
      DFSHAFT(I)=DFSHAFT(I)+RF
      DFSSHAF(I)=DFSSHAF(I)+RFS
C
C     PRINT OUT OF RESISTANCE INFORMATION FOR MODEL AND SHIP OF EACH
C     SHAFT WITH ITS REYNOLDS DEPENDENT RESISTANCE COMPONENTS
C
      PRINT 4120,VAL(I),REY,RF,RPRES,D
 4120 FORMAT(1P5E15.3,6H MODEL)
      PRINT 4130,VAL(I),REYS,RFS,RSPRES,DS
 4130 FORMAT(1P5E15.3,5H SHIP/)
 4140 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE BOSS
      COMMON ISPOT,VFW(25),VSFW(25),VRL(25),RHO,XNU,RHOS,XNUS,XLAM
      COMMON/BS/NBOSS,XLBOSS(8),RBOSS(8),ABOSS(8),DBOSS(25),DBOSSS(25),H
     1BOSS(8),DFBOSS(25),DFSBOSS(25)
      DO 5140 J=1,NBOSS
      PRINT 5100,J
 5100 FORMAT(45H1 MODEL AND SHIP SCALE RESISTANCE FOR BOSSING ,I2/)
      PRINT 5110
 5110 FORMAT(1H0,7X,4H VRL,9X,9H REYNOLDS,6X,9H FRICTION,6X,9H PRESSURE,
     16X,6H TOTAL//)
      DO 5140 I=1,ISPOT
C
C     CALCULATION OF RATIOS,CONSTANTS AND FULL-SCALE DIMENSIONS
C
      RAD=ABOSS(J)*0.017453
      RADSIN=SIN(RAD)
      RAD3=RADSIN*RADSIN*RADSIN
      XLSBOSS=XLBOSS(J)*XLAM
      RSBOSS=RBOSS(J)*XLAM
      HSBOSS=HBOSS(J)*XLAM
C
C     FLAT PLATE FRICTION COEFFICIENT BASED ON LOCAL REYNOLDS NUMBER
C
      CALL FRICT(CFBOSS,REY,VFW(I),XLBOSS(J),XNU)
      CALL FRICT(CFSBOSS,REYS,VSFW(I),XLSBOSS,XNUS)
C
C     CONSTANTS TO CONVERT DRAG COEFFICIENT TO RESISTANCE IN POUNDS
C     XM=MODEL CONSTANT
C     XS=SHIP CONSTANT
C
      XM=.5*RHO*XLBOSS(J)*RBOSS(J)*VFW(I)*VFW(I)
      XS=.5*RHOS*XLSBOSS*RSBOSS*VSFW(I)*VSFW(I)
C
C     CALCULATION OF THE BASIC PRESSURE DRAG COEFFICIENT
C
      CDBASM=PRESUR(RHO,VFW(I),RBOSS(J),HBOSS(J),XNU)
      CDBASS=PRESUR(RHOS,VSFW(I),RSBOSS,HSBOSS,XNUS)
C
C     CLACULATION OF PRESSURE DRAG CORRECTED FOR CROSSFLOW
C
      RPRES=XM*CDBASM*RAD3
      RSPRES=XS*CDBASS*RAD3
C
C     FRICTIONAL RESISTANCE
C
      RF=XM*3.14159*CFBOSS
      RFS=XS*3.14159*CFSBOSS
C
C     TOTAL OF DRAG COMPONENTS
C
      D=RPRES+RF
      DS=RSPRES+RFS
C
C     SUMMATION OF REYNOLDS DEPENDENT RESISTANCE TO OBTAIN TOTAL AMOUNT
C     FOR ALL STERNTUBE BOSSINGS AND INTERMEDIATE STRUT BARRELS COMBINED
C     PRINTED OUT FROM MAIN PROGRAM
C
      DBOSS(I)=DBOS[illegible])
      DBOSSS(I)=D[illegible])+DS
      DFBOSS(I)=D[illegible])+RF
      DFSBOSS(I)=D[illegible]S(I)+RFS
      PRINT 5120,V[illegible],REY,RF,RPRES,D
 5120 FORMAT(1P5E15.3,6H MODEL)
      PRINT 5130,VRL(I),REYS,RFS,RSPRES,DS
 5130 FORMAT(1P5E15.3,5H SHIP/)
 5140 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MAIN
      COMMON ISPOT,VFW(25),VSFW(25),VRL(25),RHO,XNU,RHOS,XNUS,XLAM
      COMMON/B6/NMAIN,XLMAIN(4),RMAIN(4),AMAIN(4),RBMAIN(4),DMAIN(25),DM
     1AINS(25),HMAIN(4),DFMAIN(25),DFSMAIN(25)
      DO 6140 J=1,NMAIN
      PRINT 6100,J
 6100 FORMAT(46H1 MODEL AND SHIP SCALE RESISTANCE FOR MAINBOSS ,I2/)
      PRINT 6110
 6110 FORMAT(1H0,7X,4H VRL,9X,9H REYNOLDS,6X,9H FRICTION,6X,9H PRESSURE,
     16X,5H BASE,10X,6H TOTAL//)
      DO 6140 I=1,ISPOT
C
C     CALCULATION OF RATIOS,CONSTANTS AND FULL-SCALE DIMENSIONS
C
      RAD=AMAIN(J)*0.0174533
      RADSIN=SIN(RAD)
      RAD3=RADSIN*RADSIN*RADSIN
      XLSMAIN=XLMAIN(J)*XLAM
      RSMAIN=RMAIN(J)*XLAM
      HSMAIN=HMAIN(J)*XLAM
      RBSMAIN=RBMAIN(J)*XLAM
C
C     FLAT PLATE FRICTION COEFFICIENT BASED ON LOCAL REYNOLDS NUMBER
C
      CALL FRICT(CFMAIN,REY,VFW(I),XLMAIN(J),XNU)
      CALL FRICT(CFSMAIN,REYS,VSFW(I),XLSMAIN,XNUS)
C
C     CONSTANTS TO CONVERT DRAG COEFFICIENT TO RESISTANCE IN POUNDS
C     XM=MODEL CONSTANT
C     XS=SHIP CONSTANT
C
      XM=.5*RHO*XLMAIN(J)*RMAIN(J)*VFW(I)*VFW(I)
      XS=.5*RHO*XLSMAIN*RSMAIN*VSFW(I)*VSFW(I)
C
C     CALCULATION OF THE BASIC PRESUSURE DRAG COEFFICIENT
C
      CDBASM=PRESUR(RHO,VFW(I),RMAIN(J),HMAIN(J),XNU)
      CDBASS=PRESUR(RHOS,VSFW(I),RSMAIN,HSMAIN,XNUS)
C
C     CALCULATION OF PRESSURE DRAG CORRECTED FOR CROSSFLOW
C
      RPRES=XM*CDBASM*RAD3
      RSPRES=XS*CDBASS*RAD3
C
C     FRICTIONAL RESISTANCE
C
      RF=XM*3.14159*CFMAIN
      RFS=XS*3.14159*CFSMAIN
C
C     BASE DRAG DUE TO BLUNTNESS OF FAIRWATER TRAILING TIP
C
      RB=(3.14159/4.)*(XM*RMAIN(J)/XLMAIN(J))*0.029*((RBMAIN(J)/RMAIN(J)
     1)**3)/(2.*SQRT(CFMAIN*XLMAIN(J)/RMAIN(J)))
      RBS=(3.14159/4.)*(XS*RSMAIN/XLSMAIN)*0.029*((RBSMAIN/RSMAIN)**3)/(
     12.*SQRT(CFSMAIN*XLSMAIN/RSMAIN))
C
C     TOTAL OF DRAG COMPONENTS
C
      D=RPRES+RF+RB
      DS=RSPRES+RFS+RBS
C
C     SUMMATION OF REYNOLDS DEPENDENT RESISTANCE TO OBTAIN TOTAL AMOUNT
C     FOR ALL MAIN STRUT BARRELS COMBINED-PRINT OUT FROM MAIN PROGRAM
C
      DMAIN(I)=DMAIN(I)+D
      DMAINS(I)=DMAINS(I)+DS
      DFMAIN(I)=DFMAIN(I)+RF
      DFSMAIN(I)=DFSMAIN(I)+RFS
C
C     PRINT OUT OF RESISTANCE INFORMATION FOR MODEL AND SHIP OF EACH
C     MAIN STRUT BARREL WITH ITS REYNOLDS DEPENDENT RESISTANCE COMPONENTS
C
      PRINT 6120,VRL(I),REY,RF,RPRES,RB,D
 6120 FORMAT(1P6E15.3,6H MODEL)
      PRINT 6130,VRL(I),REYS,RFS,RSPRES,RBS,DS
 6130 FORMAT(1P6E15.3,5H SHIP/)
 6140 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE BILGE
      COMMON ISPOT,VFW(25),VSFW(25),VRL(25),RHO,XNU,RHOS,XNUS,XLAM
      COMMON/B7/NBILGE,XLBILGE(4),SBILGE(4),DBILGE(25),DBILGES(25),DFBIL
     1GE(25),DFSBILG(25)
      DO 7140 J=1,NBILGE
      PRINT 7100,J
 7100 FORMAT(48H1 MODEL AND SHIP SCALE RESISTANCE FOR BILGE KEEL ,I2/)
      PRINT 7110
 7110 FORMAT(1H0,7X,4H VRL,9X,9H REYNOLDS,6X,6H TOTAL//)
      DO 7140 I=1,ISPOT
      XLSBILG=XLBILGE(J)*XLAM
      CALL FRICT(CFBILGE,REY,VFW(I),XLBILGE(J),XNU)
      CALL FRICT(CFSBILG,REYS,VSFW(I),XLSBILG,XNUS)
      D=.5*RHO*SBILGE(J)*VFW(I)*VFW(I)*CFBILGE
      DS=.5*RHOS*SBILGE(J)*XLAM*XLAM*VSFW(I)*VSFW(I)*CFSBILG
      DBILGE(I)=DBILGE(I)+D
      DBILGES(I)=DBILGES(I)+DS
      DFBILGE(I)=DFBILGE(I)+D
      DFSBILG(I)=DFSBILG(I)+DS
      PRINT 7120,VRL(I),REY,D
 7120 FORMAT(1P3E15.3,6H MODEL)
      PRINT 7130,VRL(I),REYS,DS
 7130 FORMAT(1P3E15.3,5H SHIP/)
 7140 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SKEG
      COMMON ISPOT,VFW(25),VSFW(25),VRL(25),RHO,XNU,RHOS,XNUS,XLAM
      COMMON/B8/NSKEG,XLSKEG(4),SSKEG(4),DSKEG(25),DSKEGS(25),DFSKEG(25)
     1,DFSSKEG(25)
      DO 8140 J=1,NSKEG
      PRINT 8100,J
 8100 FORMAT(42H1 MODEL AND SHIP SCALE RESISTANCE FOR SKEG ,I2/)
      PRINT 8110
 8110 FORMAT(1H0,7X,4H VRL,9X,9H REYNOLDS,6X,6H TOTAL//)
      DO 8140 I=1,ISPOT
      XLSSKEG=XLSKEG(J)*XLAM
      CALL FRICT(CFSKEG,REY,VFW(I),XLSKEG(J),XNU)
      CALL FRICT(CFSSKEG,REYS,VSFW(I),XLSSKEG,XNUS)
      D=.5*RHO*SSKEG(J)*VFW(I)*VFW(I)*CFSKEG
      DS=.5*RHOS*SSKEG(J)*XLAM*XLAM*VSFW(I)*VSFW(I)*CFSSKEG
      DSKEG(I)=DSKEG(I)+D
      DSKEGS(I)=DSKEGS(I)+DS
      DFSKEG(I)=DFSKEG(I)+D
      DFSSKEG(I)=DFSSKEG(I)+DS
      PRINT 8120,VRL(I),REY,D
 8120 FORMAT(1P3E15.3,6H MODEL)
      PRINT 8130,VRL(I),REYS,DS
 8130 FORMAT(1P3E15.3,5H SHIP/)
 8140 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FOILSEC(XM,XS,CF,CFS,TOC,TOC2,TOC4,S,SS,T2,TS2,SR,SRS,C
     $LOTR,RF,RFS,RFVA,RFVAS,RP,RPS,RINT,RINTS,RB,RBS)
C
C     FLAT PLATE FRICTION RESISTANCE
C
      RF=XM*2.*CF
      RFS=XS*2.*CFS
C
C     RESISTANCE DUE TO VELOCITY AUGMENTATION
C
      RFVA=XM*4.*CF*TOC
      RFVAS=XS*4.*CFS*TOC
C
C     RESISTANCE DUE TO PRESSURE OR SEPARATION (VISCOUS IN NATURE)
C
      RP=XM*120.*CF*TOC4
      RPS=XS*120.*CFS*TOC4
C
C     ADDED RESISTANCE DUE TO INTERSECTION WITH HULL
C
      RINT=(XM/S)*T2*((.75*TOC)-(.0003/TOC2))
      RINTS=(XS/SS)*TS2*((.75*TOC)-(.0003/TOC2))
C
C     BASE DRAG DUE TO BLUNTNESS OF TRAILING EDGE
C
      IF(SR.LE.0.) GO TO 9000
      RB=(XM/S)*SR*(.135/((CLOTR*CF)**(1./3.)))
      RBS=(XS/SS)*SRS*(.135/((CLOTR*CFS)**(1./3.)))
 9000 RB=0.
      RBS=0.
      RETURN
      END
```

```
      SUBROUTINE FRICT(CF,RE,VF,XLEN,XNU)
      RE=VF*XLEN*100000./XNU
      IF(RE.LT.50000.) GO TO 30
      CFTURB=.075/ALOG10(RE/100.)**2
      Y=CFTURB
   10 CFTURB=.058564/ALOG10(RE*Y)**2
      IF(ABS(CFTURB-Y).LE.1.0E-07) GO TO 20
      Y=(CFTURB+Y)/2.
      GO TO 10
   20 CF=CFTURB-(143.18/RE)
      RETURN
   30 CF=1.328/SQRT(RE)
      RETURN
      END
```

```
      FUNCTION PRESUR(RO,V,DIA,H,XN)
      RN=V*DIA*100000./XN
      SIGMA=(2083.+32.2*RO*H)/(.5*RO*V*V)
      SIGMA2=SIGMA*SIGMA
      SIGMA3=SIGMA*SIGMA2
      SIGMA4=SIGMA*SIGMA3
      SIGMA5=SIGMA*SIGMA4
      IF(RN-500000.) 10,20,20
   10 IF(SIGMA-2.5) 30,40,40
   30 PRESUR=.500425+.498891*SIGMA-.051852*SIGMA2+.0461504*SIGMA3-.06115
     11*SIGMA4+.0144903*SIGMA5
      GO TO 100
   40 PRESUR=1.17
      GO TO 100
   20 IF(SIGMA.GT.2.1.AND.SIGMA.LT.2.5) GO TO 50
      IF(SIGMA.GE.2.5) GO TO 60
      IF(SIGMA.LE.2.1) GO TO 70
   50 PRESUR=6.125-2.25*SIGMA
      GO TO 100
   60 PRESUR=0.5
      GO TO 100
   70 PRESUR=.500089+.499596*SIGMA-.0385078*SIGMA2+.00486754*SIGMA3
  100 CONTINUE
      RETURN
      END
```

APPENDIX II - INPUT FORMAT FOR COMPUTER PROGRAM APPEND

CARD	ENTRY	FORMAT	FIELD	REMARKS
1	NCASE	I5	1-5	Number of cases to be calculated
2	TITLE	13A5	1-65	Used to identify the case
3	ISPOT	I5	1-5	Number of speeds to be calculated
	SM	F10.5	6-15	Wetted surface of appendages, ft^2
	RHO	F10.5	16-25	Model water density, $slugs/ft^3$
	XNU	F10.5	26-35	Model water kinematic viscosity x 10^5, ft^2/sec
	RHOS	F10.5	36-45	Ship water density, $slugs/ft^3$
	XNUS	F10.5	46-55	Ship water kinematic viscosity x 10^5, ft^2/sec
	XLAM	F10.5	56-65	Ship-model linear ratio
	XLSHIP	F10.5	66-75	Ship length, ft
4	NRUD	I5	1-5	Number of rudders - 0 to 4
	NSTRUT	I5	6-10	Number of struts - 0-16
	NSHAFT	I5	11-15	Number of shafts - 0 to 8
	NBOSS	I5	16-20	Number of sterntube bossings and intermediate strut barrels - 0 to 8
	NMAIN	I5	21-25	Number of main strut barrels - 0 to 4
	NBILGE	I5	26-30	Number of bilge keels - 0 to 4
	NSKEG	I5	31-35	Number of skegs - 0 to 4
	NFIN	I5	36-40	Number of stabilizer fins - 0 to 4
THE NEXT ISPOT CARDS	VS	F10.5	1-10	Ship speed in knots
•	1-WT	F10.F	11-20	Wake fraction
•	•	•	•	
•	•	•	•	
•	•	•	•	
THE NEXT NRUD CARDS	SRUD	F10.5	1-10	Rudder planform area for one side, ft^2
	TRUD	F10.5	11-20	Rudder maximum thickness, ft

INPUT FORMAT FOR APPEND (CON'T)

CARD	ENTRY	FORMAT	FIELD	REMARKS
	CRUD	F10.5	21-30	Rudder maximum chord, ft
	TBRUD	F10.5	31-40	Thickness of trailing edge of rudder, ft
	SBRUD	F10.5	41-50	Projected area of blunt edge of rudder, ft^2
	.	.	.	
	.	.	.	
	.	.	.	
THE NEXT NSTRUT CARDS	SSTRUT	F10.5	1-10	Strut planform area for one side, ft^2
	TSTRUT	F10.5	11-20	Strut maximum thickness, ft
	CSTRUT	F10.5	21-30	Strut maximum chord, ft
	TBSTRUT	F10.5	31-40	Thickness of trailing edge of strut, ft
	SBSTRUT	F10.5	41-50	Projected area of blunt edge of strut, ft^2
	.	.	.	
	.	.	.	
	.	.	.	
THE NEXT NFIN CARDS	SFIN	F10.5	1-10	Fin planform area for one side, ft^2
	TFIN	F10.5	11-20	Fin maximum thickness, ft
	CFIN	F10.5	21-30	Fin maximum chord, ft
	TBFIN	F10.5	31-40	Thickness of trailing edge of fin, ft
	SBFIN	F10.5	41-50	Projected area of blunt edge of strut, ft^2
	.	.	.	
	.	.	.	
	.	.	.	

INPUT FORMAT FOR APPEND (CONT'D)

CARD	ENTRY	FORMAT	FIELD	REMARKS
THE NEXT NSHAFT CARDS	XLSHAFT	F10.5	1-10	Shaft length, ft
	RSHAFT	F10.5	11-20	Shaft diameter, ft
	ASHAFT	F10.5	21-30	Angle of flow, degrees
	HSHAFT	F10.5	31-40	Depth below waterline to shaft, ft
	.	.	.	
	.	.	.	
	.	.	.	
THE NEXT NBOSS CARDS	XLBOSS	F10.5	1-10	Bossing and/or intermediate strut barrel length, ft
	RBOSS	F10.5	11-20	Bossing and/cr intermediate strut barrel diameter
	ABOSS	F10.5	21-30	Angle of flow, degrees
	HBOSS	F10.5	31-40	Depth below waterline to bossing and/or intermediate strut barrel, ft
	.	.	.	
	.	.	.	
	.	.	.	
THE NEXT NMAIN CARDS	XLMAIN	F10.5	1-10	Main strut barrel length, ft
	RMAIN	F10.5	11-20	Main strut barrel diameter, ft
	AMAIN	F10.5	21-30	Angle of flow, degrees
	HMAIN	F10.5	31-40	Depth below water to main strut barrel, ft
	RBMAIN	F10.5	41-50	Diameter of fairwater ending, ft.

INPUT FORMAT FOR APPEND (CONT'D)

CARD	ENTRY	FORMAT	FIELD	REMARKS
THE NEXT NBILGE CARDS	LBILGE	F10.5	1-10	Bilge keel length, ft
	SBILGE	F10.5	11-20	Bilge keel wetted surface ft^2 (as described in text)
	•	•	•	
	•	•	•	
	•	•	•	
THE NEXT NSKEG CARDS	LSKEG	F10.5	1-10	Skeg length, ft
	SSKEG	F10.5	11-20	Skeg wetted surface, ft^2 (as described in text)
	•	•	•	
	•	•	•	
	•	•	•	

START THE NEXT CASE BEGINNING WITH CARD #2

APPENDIX III - OUTPUT

The output formats of "Append" have been written so as to give the user detailed information about the drag of his appendages. First, the drag components of each individual appendage are printed out, this includes the speed-length ratio based on the length of the hull and the local Reynolds number. Next, the total calculated frictional resistance components are printed and finally the total calculated viscous resistance is printed. The program will output the above information for both the model and the full-scale appendages.

MODEL AND SHIP SCALE RESISTANCE FOR RUDDER 1

VEL	REYNOLDS	FLAT PLATE	VEL AUG	PRESSURE	INTERSECT	BASE	TOTAL	
5.237E-01	1.656E+05	3.877E-02	1.513E-02	3.369E-03	1.517E-02	0.	7.243E-02	MODEL
5.237E-01	1.646E+07	2.908E+02	1.135E+02	2.527E+01	2.333E+02	0.	6.628E+02	SHIP
5.674E-01	1.796E+05	4.520E-02	1.764E-02	3.928E-03	1.784E-02	0.	8.461E-02	MODEL
5.674E-01	1.785E+07	3.377E+02	1.318E+02	2.935E+01	2.743E+02	0.	7.732E+02	SHIP
6.110E-01	1.936E+05	5.209E-02	2.032E-02	4.527E-03	2.074E-02	0.	9.768E-02	MODEL
6.110E-01	1.924E+07	3.880E+02	1.514E+02	3.372E+01	3.188E+02	0.	8.919E+02	SHIP
6.547E-01	2.083E+05	5.977E-02	2.332E-02	5.194E-03	2.400E-02	0.	1.123E-01	MODEL
6.547E-01	2.070E+07	4.440E+02	1.732E+02	3.858E+01	3.689E+02	0.	1.025E+03	SHIP
6.983E-01	2.222E+05	6.748E-02	2.633E-02	5.864E-03	2.730E-02	0.	1.270E-01	MODEL
6.983E-01	2.208E+07	5.002E+02	1.952E+02	4.347E+01	4.197E+02	0.	1.159E+03	SHIP
7.419E-01	2.356E+05	7.531E-02	2.938E-02	6.545E-03	3.070E-02	0.	1.419E-01	MODEL
7.419E-01	2.341E+07	5.574E+02	2.175E+02	4.844E+01	4.720E+02	0.	1.295E+03	SHIP
7.856E-01	2.497E+05	8.397E-02	3.276E-02	7.297E-03	3.449E-02	0.	1.585E-01	MODEL
7.856E-01	2.481E+07	6.207E+02	2.422E+02	5.394E+01	5.302E+02	0.	1.447E+03	SHIP
8.292E-01	2.636E+05	9.290E-02	3.625E-02	8.073E-03	3.843E-02	0.	1.756E-01	MODEL
8.292E-01	2.619E+07	6.860E+02	2.676E+02	5.961E+01	5.907E+02	0.	1.604E+03	SHIP
8.729E-01	2.775E+05	1.022E-01	3.989E-02	8.884E-03	4.258E-02	0.	1.936E-01	MODEL
8.729E-01	2.757E+07	7.542E+02	2.943E+02	6.554E+01	6.545E+02	0.	1.769E+03	SHIP
9.165E-01	2.913E+05	1.120E-01	4.368E-02	9.729E-03	4.694E-02	0.	2.123E-01	MODEL
9.165E-01	2.895E+07	8.255E+02	3.221E+02	7.173E+01	7.216E+02	0.	1.941E+03	SHIP
9.602E-01	3.052E+05	1.221E-01	4.763E-02	1.061E-02	5.152E-02	0.	2.318E-01	MODEL
9.602E-01	3.032E+07	8.997E+02	3.510E+02	7.818E+01	7.920E+02	0.	2.121E+03	SHIP
1.004E+00	3.191E+05	1.326E-01	5.174E-02	1.152E-02	5.631E-02	0.	2.522E-01	MODEL
1.004E+00	3.170E+07	9.768E+02	3.811E+02	8.488E+01	8.656E+02	0.	2.308E+03	SHIP
1.047E+00	3.330E+05	1.435E-01	5.600E-02	1.247E-02	6.131E-02	0.	2.733E-01	MODEL
1.047E+00	3.308E+07	1.057E+03	4.123E+02	9.184E+01	9.425E+02	0.	2.504E+03	SHIP
1.091E+00	3.468E+05	1.548E-01	6.040E-02	1.345E-02	6.653E-02	0.	2.952E-01	MODEL
1.091E+00	3.446E+07	1.140E+03	4.447E+02	9.905E+01	1.023E+03	0.	2.706E+03	SHIP
1.135E+00	3.607E+05	1.665E-01	6.496E-02	1.447E-02	7.195E-02	0.	3.179E-01	MODEL
1.135E+00	3.584E+07	1.226E+03	4.782E+02	1.065E+02	1.106E+03	0.	2.917E+03	SHIP
1.178E+00	3.734E+05	1.776E-01	6.928E-02	1.543E-02	7.713E-02	0.	3.394E-01	MODEL
1.178E+00	3.710E+07	1.307E+03	5.100E+02	1.136E+02	1.186E+03	0.	3.116E+03	SHIP
1.222E+00	3.884E+05	1.910E-01	7.452E-02	1.660E-02	8.345E-02	0.	3.656E-01	MODEL
1.222E+00	3.859E+07	1.406E+03	5.486E+02	1.222E+02	1.283E+03	0.	3.360E+03	SHIP
1.266E+00	4.039E+05	2.053E-01	8.011E-02	1.784E-02	9.024E-02	0.	3.935E-01	MODEL
1.266E+00	4.013E+07	1.512E+03	5.898E+02	1.314E+02	1.387E+03	0.	3.620E+03	SHIP
1.309E+00	4.187E+05	2.194E-01	8.561E-02	1.907E-02	9.696E-02	0.	4.211E-01	MODEL
1.309E+00	4.160E+07	1.616E+03	6.304E+02	1.404E+02	1.491E+03	0.	3.877E+03	SHIP

SHIP AND MODEL SCALE RESISTANCE FOR STRUT 1

VRL	REYNOLDS	FLAT PLATE	VEL AUG	PRESSURE	INTERSECT	BASE	TOTAL	
5.237E-01	4.228E+04	4.932E-03	9.429E-04	2.471E-05	1.333E-04	0.	6.033E-03	MODEL
5.237E-01	4.201E+06	3.944E+01	7.541E+00	1.976E-01	2.050E+00	0.	4.923E+01	SHIP
5.674E-01	4.585E+04	5.569E-03	1.065E-03	2.7[illegible]1E-05	1.568E-04	0.	6.819E-03	MODEL
5.674E-01	4.556E+06	4.577E+01	8.751E+00	2.293E-01	2.411E+00	0.	5.716E+01	SHIP
6.110E-01	4.943E+04	6.234E-03	1.192E-03	3.124E-05	1.822E-04	0.	7.639E-03	MODEL
6.110E-01	4.911E+06	5.254E+01	1.004E+01	2.633E-01	2.801E+00	0.	6.565E+01	SHIP
6.547E-01	5.317E+04	6.838E-03	1.307E-03	3.426E-05	2.109E-04	0.	8.390E-03	MODEL
6.547E-01	5.283E+06	6.008E+01	1.149E+01	3.010E-01	3.242E+00	0.	7.511E+01	SHIP
6.983E-01	5.672E+04	7.830E-03	1.497E-03	3.924E-05	2.399E-04	0.	9.606E-03	MODEL
6.983E-01	5.635E+06	6.764E+01	1.293E+01	3.389E-01	3.688E+00	0.	8.460E+01	SHIP
7.419E-01	6.014E+04	8.845E-03	1.691E-03	4.432E-05	2.698E-04	0.	1.085E-02	MODEL
7.419E-01	5.975E+06	7.533E+01	1.440E+01	3.775E-01	4.147E+00	0.	9.426E+01	SHIP
7.856E-01	6.374E+04	9.972E-03	1.906E-03	4.997E-05	3.031E-04	0.	1.223E-02	MODEL
7.856E-01	6.333E+06	8.383E+01	1.603E+01	4.201E-01	4.659E+00	0.	1.049E+02	SHIP
8.292E-01	6.729E+04	1.114E-02	2.129E-03	5.581E-05	3.377E-04	0.	1.366E-02	MODEL
8.292E-01	6.685E+06	9.259E+01	1.770E+01	4.640E-01	5.191E+00	0.	1.159E+02	SHIP
8.729E-01	7.083E+04	1.236E-02	2.363E-03	6.194E-05	3.741E-04	0.	1.516E-02	MODEL
8.729E-01	7.037E+06	1.017E+02	1.945E+01	5.098E-01	5.752E+00	0.	1.275E+02	SHIP
9.165E-01	7.437E+04	1.364E-02	2.608E-03	6.835E-05	4.125E-04	0.	1.673E-02	MODEL
9.165E-01	7.389E+06	1.113E+02	2.128E+01	5.577E-01	6.341E+00	0.	1.395E+02	SHIP
9.602E-01	7.791E+04	1.498E-02	2.864E-03	7.505E-05	4.527E-04	0.	1.837E-02	MODEL
9.602E-01	7.741E+06	1.212E+02	2.318E+01	6.075E-01	6.960E+00	0.	1.520E+02	SHIP
1.004E+00	8.145E+04	1.637E-02	3.130E-03	8.203E-05	4.948E-04	0.	2.008E-02	MODEL
1.004E+00	8.092E+06	1.316E+02	2.516E+01	6.593E-01	7.607E+00	0.	1.650E+02	SHIP
1.047E+00	8.499E+04	1.782E-02	3.406E-03	8.928E-05	5.388E-04	0.	2.185E-02	MODEL
1.047E+00	8.444E+06	1.423E+02	2.720E+01	7.130E-01	8.282E+00	0.	1.785E+02	SHIP
1.091E+00	8.853E+04	1.932E-02	3.693E-03	9.680E-05	5.846E-04	0.	2.369E-02	MODEL
1.091E+00	8.796E+06	1.534E+02	2.933E+01	7.686E-01	8.987E+00	0.	1.925E+02	SHIP
1.135E+00	9.207E+04	2.087E-02	3.991E-03	1.046E-04	6.323E-04	0.	2.560E-02	MODEL
1.135E+00	9.148E+06	1.649E+02	3.152E+01	8.261E-01	9.720E+00	0.	2.069E+02	SHIP
1.178E+00	9.533E+04	2.235E-02	4.273E-03	1.120E-04	6.778E-04	0.	2.741E-02	MODEL
1.178E+00	9.471E+06	1.758E+02	3.360E+01	8.807E-01	1.042E+01	0.	2.207E+02	SHIP
1.222E+00	9.916E+04	2.415E-02	4.617E-03	1.210E-04	7.333E-04	0.	2.962E-02	MODEL
1.222E+00	9.852E+06	1.890E+02	3.613E+01	9.469E-01	1.127E+01	0.	2.373E+02	SHIP
1.266E+00	1.031E+05	2.607E-02	4.984E-03	1.306E-04	7.930E-04	0.	3.197E-02	MODEL
1.266E+00	1.024E+07	2.031E+02	3.883E+01	1.018E+00	1.219E+01	0.	2.551E+02	SHIP
1.309E+00	1.069E+05	2.796E-02	5.345E-03	1.401E-04	8.520E-04	0.	3.429E-02	MODEL
1.309E+00	1.062E+07	2.170E+02	4.148E+01	1.087E+00	1.310E+01	0.	2.726E+02	SHIP

SHIP AND MODEL SCALE RESISTANCE FOR FIN 1

VRL	REYNOLDS	FLAT PLATE	VEL AUG	PRESSURE	INTERSECT	BASE	TOTAL	
4.226E-01	2.008E+04	2.432E-03	8.110E-04	1.128E-04	2.620E-04	0.	3.618E-03	MODEL
4.226E-01	1.901E+06	1.425E+01	4.753E+00	6.607E-01	3.753E+00	0.	2.342E+01	SHIP
5.071E-01	2.410E+04	3.197E-03	1.066E-03	1.482E-04	3.773E-04	0.	4.789E-03	MODEL
5.071E-01	2.281E+06	1.991E+01	6.639E+00	9.229E-01	5.405E+00	0.	3.288E+01	SHIP
5.494E-01	2.611E+04	3.605E-03	1.202E-03	1.671E-04	4.428E-04	0.	5.417E-03	MODEL
5.494E-01	2.472E+06	2.306E+01	7.688E+00	1.069E+00	6.343E+00	0.	3.816E+01	SHIP
5.916E-01	2.812E+04	4.029E-03	1.343E-03	1.868E-04	5.135E-04	0.	6.073E-03	MODEL
5.916E-01	2.662E+06	2.641E+01	8.807E+00	1.224E+00	7.357E+00	0.	4.380E+01	SHIP
6.339E-01	3.013E+04	4.468E-03	1.490E-03	2.071E-04	5.895E-04	0.	6.755E-03	MODEL
6.339E-01	2.852E+06	2.997E+01	9.994E+00	1.389E+00	8.445E+00	0.	4.980E+01	SHIP
6.761E-01	3.213E+04	4.923E-03	1.641E-03	2.282E-04	6.707E-04	0.	7.463E-03	MODEL
6.761E-01	3.042E+06	3.374E+01	1.125E+01	1.564E+00	9.609E+00	0.	5.616E+01	SHIP
7.184E-01	3.414E+04	5.391E-03	1.798E-03	2.499E-04	7.571E-04	0.	8.196E-03	MODEL
7.184E-01	3.232E+06	3.771E+01	1.257E+01	1.748E+00	1.085E+01	0.	6.287E+01	SHIP
7.606E-01	3.615E+04	5.874E-03	1.959E-03	2.723E-04	8.488E-04	0.	8.954E-03	MODEL
7.606E-01	3.422E+06	4.187E+01	1.396E+01	1.941E+00	1.216E+01	0.	6.994E+01	SHIP
8.029E-01	3.816E+04	6.370E-03	2.124E-03	2.953E-04	9.458E-04	0.	9.735E-03	MODEL
8.029E-01	3.612E+06	4.624E+01	1.542E+01	2.144E+00	1.355E+01	0.	7.735E+01	SHIP
8.452E-01	4.017E+04	6.880E-03	2.[illegible]94E-03	3.189E-04	1.048E-03	0.	1.054E-02	MODEL
8.452E-01	3.802E+06	5.080E+01	1.694E+01	2.355E+00	1.501E+01	0.	8.511E+01	SHIP
8.874E-01	4.218E+04	7.402E-03	2.468E-03	3.431E-04	1.155E-03	0.	1.137E-02	MODEL
8.874E-01	3.993E+06	5.556E+01	1.853E+01	2.576E+00	1.655E+01	0.	9.322E+01	SHIP
9.297E-01	4.413E+04	7.937E-03	2.647E-03	3.679E-04	1.268E-03	0.	1.222E-02	MODEL
9.297E-01	4.163E+06	6.051E+01	2.018E+01	2.805E+00	1.817E+01	0.	1.017E+02	SHIP
9.719E-01	4.619E+04	8.484E-03	2.829E-03	3.933E-04	1.386E-03	0.	1.309E-02	MODEL
9.719E-01	4.373E+06	6.564E+01	2.189E+01	3.044E+00	1.966E+01	0.	1.105E+02	SHIP
1.014E+00	4.820E+04	9.044E-03	3.015E-03	4.192E-04	1.509E-03	0.	1.399E-02	MODEL
1.014E+00	4.563E+06	7.099E+01	2.367E+01	3.291E+00	2.162E+01	0.	1.196E+02	SHIP
1.056E+00	5.021E+04	9.121E-03	3.041E-03	4.228E-04	1.637E-03	0.	1.422E-02	MODEL
1.056E+00	4.753E+06	7.652E+01	2.551E+01	3.547E+00	2.346E+01	0.	1.290E+02	SHIP
1.099E+00	5.222E+04	9.914E-03	3.306E-03	4.596E-04	1.771E-03	0.	1.545E-02	MODEL
1.099E+00	4.943E+06	8.223E+01	2.742E+01	3.812E+00	2.537E+01	0.	1.388E+02	SHIP
1.141E+00	5.423E+04	1.074E-02	3.580E-03	4.977E-04	1.910E-03	0.	1.672E-02	MODEL
1.141E+00	5.133E+06	8.814E+01	2.939E+01	4.086E+00	2.736E+01	0.	1.490E+02	SHIP
1.183E+00	5.623E+04	1.159E-02	3.86[illegible]E-03	5.371E-04	2.054E-03	0.	1.804E-02	MODEL
1.183E+00	5.323E+06	9.423E+01	3.142E+01	4.368E+00	2.943E+01	0.	1.594E+02	SHIP
1.225E+00	5.836E+04	1.252E-02	4.175E-03	5.804E-04	2.212E-03	0.	1.949E-02	MODEL
1.225E+00	5.525E+06	1.009E+02	3.364E+01	4.677E+00	3.170E+01	0.	1.709E+02	SHIP

MODEL AND SHIP SCALE RESISTANCE FOR SHAFT 1

VRL	REYNOLDS	FRICTION	PRESSURE	TOTAL	
5.237E-01	5.011E+05	2.547E-02	2.885E-03	2.835E-02	MODEL
5.237E-01	4.978E+07	1.878E+02	1.895E+01	2.067E+02	SHIP
5.674E-01	5.434E+05	2.957E-02	3.393E-03	3.297E-02	MODEL
5.674E-01	5.399E+07	2.182E+02	2.229E+01	2.405E+02	SHIP
6.110E-01	5.858E+05	3.396E-02	3.943E-03	3.790E-02	MODEL
6.110E-01	5.820E+07	2.509E+02	2.590E+01	2.768E+02	SHIP
6.547E-01	6.301E+05	3.885E-02	4.562E-03	4.341E-02	MODEL
6.547E-01	6.261E+07	2.873E+02	2.997E+01	3.172E+02	SHIP
6.983E-01	6.721E+05	4.374E-02	5.191E-03	4.893E-02	MODEL
6.983E-01	6.678E+07	3.238E+02	3.410E+01	3.579E+02	SHIP
7.419E-01	7.127E+05	4.872E-02	5.837E-03	5.456E-02	MODEL
7.419E-01	7.081E+07	3.611E+02	3.835E+01	3.994E+02	SHIP
7.856E-01	7.554E+05	5.422E-02	6.557E-03	6.077E-02	MODEL
7.856E-01	7.505E+07	4.023E+02	4.308E+01	4.454E+02	SHIP
8.292E-01	7.974E+05	5.988E-02	7.305E-03	6.718E-02	MODEL
8.292E-01	7.922E+07	4.448E+02	4.800E+01	4.928E+02	SHIP
8.729E-01	8.393E+05	6.579E-02	8.095E-03	7.389E-02	MODEL
8.729E-01	8.339E+07	4.893E+02	5.318E+01	5.425E+02	SHIP
9.165E-01	8.813E+05	7.196E-02	8.924E-03	8.088E-02	MODEL
9.165E-01	8.756E+07	5.357E+02	6.721E+01	6.029E+02	SHIP
9.602E-01	9.233E+05	7.837E-02	9.795E-03	8.817E-02	MODEL
9.602E-01	9.173E+07	5.841E+02	1.372E+02	7.214E+02	SHIP
1.004E+00	9.652E+05	8.503E-02	1.071E-02	9.574E-02	MODEL
1.004E+00	9.590E+07	6.345E+02	1.994E+02	8.339E+02	SHIP
1.047E+00	1.007E+06	9.194E-02	1.166E-02	1.036E-01	MODEL
1.047E+00	1.001E+08	6.867E+02	2.064E+02	8.931E+02	SHIP
1.091E+00	1.049E+06	9.909E-02	1.265E-02	1.117E-01	MODEL
1.091E+00	1.042E+08	7.409E+02	2.136E+02	9.545E+02	SHIP
1.135E+00	1.091E+06	1.065E-01	1.368E-02	1.202E-01	MODEL
1.135E+00	1.084E+08	7.970E+02	2.211E+02	1.018E+03	SHIP
1.178E+00	1.130E+06	1.135E-01	1.466E-02	1.281E-01	MODEL
1.178E+00	1.122E+08	8.502E+02	2.281E+02	1.078E+03	SHIP
1.222E+00	1.175E+06	1.220E-01	1.587E-02	1.378E-01	MODEL
1.222E+00	1.167E+08	9.149E+02	2.367E+02	1.152E+03	SHIP
1.266E+00	1.222E+06	1.310E-01	1.716E-02	1.482E-01	MODEL
1.266E+00	1.214E+08	9.840E+02	2.459E+02	1.230E+03	SHIP
1.309E+00	1.267E+06	1.400E-01	1.843E-02	1.584E-01	MODEL
1.309E+00	1.258E+08	1.052E+03	2.549E+02	1.307E+03	SHIP

MODEL AND SHIP SCALE RESISTANCE FOR BOSSING 1

VRL	REYNOLDS	FRICTION	PRESSURE	TOTAL	
5.237E-01	2.489E+05	2.346E-02	4.463E-03	2.792E-02	MODEL
5.237E-01	2.473E+07	1.734E+02	2.932E+01	2.027E+02	SHIP
5.674E-01	2.699E+05	2.730E-02	5.248E-03	3.254E-02	MODEL
5.674E-01	2.682E+07	2.015E+02	3.448E+01	2.359E+02	SHIP
6.110E-01	2.910E+05	3.140E-02	6.099E-03	3.750E-02	MODEL
6.110E-01	2.891E+07	2.315E+02	4.007E+01	2.716E+02	SHIP
6.547E-01	3.130E+05	3.597E-02	7.056E-03	4.303E-02	MODEL
6.547E-01	3.110E+07	2.650E+02	4.637E+01	3.114E+02	SHIP
6.983E-01	3.339E+05	4.055E-02	8.031E-03	4.858E-02	MODEL
6.983E-01	3.318E+07	2.986E+02	5.276E+01	3.514E+02	SHIP
7.419E-01	3.541E+05	4.521E-02	9.030E-03	5.424E-02	MODEL
7.419E-01	3.518E+07	3.328E+02	5.932E+01	3.922E+02	SHIP
7.856E-01	3.753E+05	5.035E-02	1.014E-02	6.050E-02	MODEL
7.856E-01	3.728E+07	3.707E+02	6.664E+01	4.373E+02	SHIP
8.292E-01	3.961E+05	5.566E-02	1.130E-02	6.696E-02	MODEL
8.292E-01	3.936E+07	4.097E+02	7.425E+01	4.840E+02	SHIP
8.729E-01	4.170E+05	6.120E-02	1.252E-02	7.372E-02	MODEL
8.729E-01	4.143E+07	4.506E+02	8.227E+01	5.328E+02	SHIP
9.165E-01	4.378E+05	6.697E-02	1.381E-02	8.078E-02	MODEL
9.165E-01	4.350E+07	4.932E+02	1.448E+02	6.380E+02	SHIP
9.602E-01	4.587E+05	7.298E-02	1.515E-02	8.813E-02	MODEL
9.602E-01	4.557E+07	5.376E+02	2.531E+02	7.907E+02	SHIP
1.004E+00	4.795E+05	7.922E-02	1.656E-02	9.578E-02	MODEL
1.004E+00	4.764E+07	5.838E+02	3.009E+02	8.847E+02	SHIP
1.047E+00	5.004E+05	8.569E-02	1.803E-02	1.037E-01	MODEL
1.047E+00	4.971E+07	6.318E+02	3.117E+02	9.434E+02	SHIP
1.091E+00	5.212E+05	9.239E-02	1.957E-02	1.120E-01	MODEL
1.091E+00	5.178E+07	6.814E+02	3.228E+02	1.004E+03	SHIP
1.135E+00	5.421E+05	9.932E-02	2.116E-02	1.205E-01	MODEL
1.135E+00	5.386E+07	7.329E+02	3.343E+02	1.067E+03	SHIP
1.178E+00	5.612E+05	1.059E-01	2.269E-02	1.286E-01	MODEL
1.178E+00	5.576E+07	7.816E+02	3.452E+02	1.127E+03	SHIP
1.222E+00	5.838E+05	1.138E-01	2.454E-02	1.364E-01	MODEL
1.222E+00	5.800E+07	8.409E+02	3.585E+02	1.199E+03	SHIP
1.266E+00	6.070E+05	1.223E-01	2.654E-02	1.489E-01	MODEL
1.266E+00	6.031E+07	9.042E+02	3.726E+02	1.277E+03	SHIP
1.309E+00	6.292E+05	1.307E-01	2.852E-02	1.592E-01	MODEL
1.309E+00	6.252E+07	9.665E+02	3.864E+02	1.353E+03	SHIP

MODEL AND SHIP SCALE RESISTANCE FOR MAINROSS I

VRL	REYNOLDS	FRICTION	PRESSURE	BASE	TOTAL	
5.237E-01	2.360E+05	2.239E-02	4.231E-03	0.	2.662E-02	MODEL
5.237E-01	2.344E+07	1.612E+02	2.704E+01	0.	1.882E+02	SHIP
5.474E-01	2.559E+05	2.606E-02	4.975E-03	0.	3.103E-02	MODEL
5.474E-01	2.547E+07	1.873E+02	3.179E+01	0.	2.190E+02	SHIP
6.110E-01	2.759E+05	2.998E-02	5.782E-03	0.	3.576E-02	MODEL
6.110E-01	2.741E+07	2.152E+02	3.695E+01	0.	2.521E+02	SHIP
6.547E-01	2.967E+05	3.435E-02	6.691E-03	0.	4.104E-02	MODEL
6.547E-01	2.948E+07	2.463E+02	4.276E+01	0.	2.890E+02	SHIP
6.983E-01	3.165E+05	3.873E-02	7.613E-03	0.	4.635E-02	MODEL
6.983E-01	3.145E+07	2.775E+02	4.865E+01	0.	3.262E+02	SHIP
7.419E-01	3.356E+05	4.319E-02	8.560E-03	0.	5.175E-02	MODEL
7.419E-01	3.335E+07	3.093E+02	5.470E+01	0.	3.640E+02	SHIP
7.856E-01	3.557E+05	4.811E-02	9.616E-03	0.	5.773E-02	MODEL
7.856E-01	3.534E+07	3.445E+02	6.145E+01	0.	4.059E+02	SHIP
8.292E-01	3.755E+05	5.318E-02	1.071E-02	0.	6.389E-02	MODEL
8.292E-01	3.731E+07	3.808E+02	6.846E+01	0.	4.492E+02	SHIP
8.729E-01	3.953E+05	5.848E-02	1.187E-02	0.	7.035E-02	MODEL
8.729E-01	3.927E+07	4.187E+02	7.586E+01	0.	4.946E+02	SHIP
9.165E-01	4.150E+05	6.400E-02	1.309E-02	0.	7.709E-02	MODEL
9.165E-01	4.123E+07	4.583E+02	8.363E+01	0.	5.420E+02	SHIP
9.602E-01	4.348E+05	6.975E-02	1.436E-02	0.	8.411E-02	MODEL
9.602E-01	4.320E+07	4.996E+02	1.314E+02	0.	6.309E+02	SHIP
1.004E+00	4.546E+05	7.572E-02	1.570E-02	0.	9.142E-02	MODEL
1.004E+00	4.516E+07	5.425E+02	2.359E+02	0.	7.784E+02	SHIP
1.047E+00	4.743E+05	8.191E-02	1.710E-02	0.	9.900E-02	MODEL
1.047E+00	4.713E+07	5.870E+02	3.063E+02	0.	8.934E+02	SHIP
1.091E+00	4.941E+05	8.832E-02	1.855E-02	0.	1.069E-01	MODEL
1.091E+00	4.909E+07	6.332E+02	3.167E+02	0.	9.499E+02	SHIP
1.135E+00	5.138E+05	9.494E-02	2.006E-02	0.	1.150E-01	MODEL
1.135E+00	5.105E+07	6.810E+02	3.274E+02	0.	1.008E+03	SHIP
1.178E+00	5.320E+05	1.012E-01	2.151E-02	0.	1.227E-01	MODEL
1.178E+00	5.286E+07	7.263E+02	3.376E+02	0.	1.064E+03	SHIP
1.222E+00	5.534E+05	1.088E-01	2.327E-02	0.	1.321E-01	MODEL
1.222E+00	5.498E+07	7.813E+02	3.499E+02	0.	1.131E+03	SHIP
1.266E+00	5.754E+05	1.170E-01	2.516E-02	0.	1.421E-01	MODEL
1.266E+00	5.717E+07	8.401E+02	3.630E+02	0.	1.203E+03	SHIP
1.309E+00	5.965E+05	1.250E-01	2.703E-02	0.	1.520E-01	MODEL
1.309E+00	5.926E+07	8.980E+02	3.759E+02	0.	1.274E+03	SHIP

MODEL AND SHIP SCALE RESISTANCE FOR BILGE KEEL 1

VRL	REYNOLDS	TOTAL	
5.237E-01	2.047E+06	6.484E-02	MODEL
5.237E-01	2.034E+08	4.946E+02	SHIP
5.674E-01	2.220E+06	7.522E-02	MODEL
5.674E-01	2.205E+08	5.754E+02	SHIP
6.110E-01	2.393E+06	8.633E-02	MODEL
6.110E-01	2.377E+08	6.620E+02	SHIP
6.547E-01	2.574E+06	9.869E-02	MODEL
6.547E-01	2.555E+08	7.587E+02	SHIP
6.983E-01	2.746E+06	1.111E-01	MODEL
6.983E-01	2.728E+08	8.558E+02	SHIP
7.419E-01	2.912E+06	1.237E-01	MODEL
7.419E-01	2.893E+08	9.549E+02	SHIP
7.856E-01	3.086E+06	1.376E-01	MODEL
7.856E-01	3.066E+08	1.065E+03	SHIP
8.292E-01	3.257E+06	1.520E-01	MODEL
8.292E-01	3.236E+08	1.178E+03	SHIP
8.729E-01	3.429E+06	1.670E-01	MODEL
8.729E-01	3.407E+08	1.296E+03	SHIP
9.165E-01	3.600E+06	1.826E-01	MODEL
9.165E-01	3.577E+08	1.420E+03	SHIP
9.602E-01	3.772E+06	1.989E-01	MODEL
9.602E-01	3.747E+08	1.549E+03	SHIP
1.004E+00	3.943E+06	2.158E-01	MODEL
1.004E+00	3.918E+08	1.683E+03	SHIP
1.047E+00	4.115E+06	2.333E-01	MODEL
1.047E+00	4.088E+08	1.823E+03	SHIP
1.091E+00	4.286E+06	2.514E-01	MODEL
1.091E+00	4.258E+08	1.968E+03	SHIP
1.135E+00	4.457E+06	2.702E-01	MODEL
1.135E+00	4.429E+08	2.117E+03	SHIP
1.178E+00	4.615E+06	2.880E-01	MODEL
1.178E+00	4.585E+08	2.260E+03	SHIP
1.222E+00	4.800E+06	3.096E-01	MODEL
1.222E+00	4.769E+08	2.432E+03	SHIP
1.266E+00	4.992E+06	3.326E-01	MODEL
1.266E+00	4.960E+08	2.617E+03	SHIP
1.309E+00	5.174E+06	3.553E-01	MODEL
1.309E+00	5.141E+08	2.799E+03	SHIP

CALCULATED FLAT PLATE FRICTIONAL RESISTANCE COMPONENTFOR MODEL SCALE APPENDAGES BASED ON LOCAL REYNOLDS NUMBER-IN LBS/
THE APPENDAGE FLAT PLATE FRICTION COEFFICIENT=FRICT. DRAG(APP)/((DENSITY/2.)*(VEL.)*(VEL.)*(APPENDAGE WETTED SURFACE))

VM-KNOTS	VRL	RUDDER	STRUT	FIN	SHAFT	BOSS	MAIN	BILGE	SKEG	TOTAL	COEFFICIENT
2.418	.524	.078	.079	0.000	.112	.074	.045	.130	0.000	.517	4.7021E-03
2.619	.557	.090	.092	0.000	.131	.087	.052	.150	0.000	.602	4.6612E-03
2.821	.611	.104	.106	0.000	.150	.100	.060	.173	0.000	.692	4.6229E-03
3.022	.655	.120	.121	0.000	.171	.114	.069	.197	0.000	.793	4.6100E-03
3.224	.698	.135	.138	0.000	.193	.129	.077	.222	0.000	.895	4.5739E-03
3.425	.742	.151	.155	0.000	.215	.144	.086	.247	0.000	.999	4.5222E-03
3.626	.786	.168	.174	0.000	.239	.161	.096	.275	0.000	1.114	4.4976E-03
3.828	.829	.186	.194	0.000	.264	.178	.106	.304	0.000	1.232	4.4659E-03
4.029	.873	.204	.215	0.000	.290	.195	.117	.334	0.000	1.356	4.4355E-03
4.231	.917	.224	.237	0.000	.318	.214	.128	.365	0.000	1.485	4.4063E-03
4.432	.960	.244	.259	0.000	.346	.233	.139	.398	0.000	1.619	4.3783E-03
4.634	1.004	.265	.283	0.000	.375	.253	.151	.432	0.000	1.759	4.3514E-03
4.835	1.047	.287	.307	0.000	.406	.274	.164	.467	0.000	1.904	4.3254E-03
5.037	1.091	.310	.332	0.000	.437	.295	.177	.503	0.000	2.054	4.3005E-03
5.238	1.135	.333	.358	0.000	.470	.318	.190	.540	0.000	2.209	4.2764E-03
5.440	1.178	.355	.383	0.000	.501	.339	.202	.576	0.000	2.356	4.2295E-03
5.641	1.222	.382	.414	0.000	.538	.364	.218	.619	0.000	2.535	4.2308E-03
5.843	1.266	.411	.446	0.000	.578	.392	.234	.665	0.000	2.725	4.2406E-03
6.044	1.309	.439	.478	0.000	.618	.418	.250	.711	0.000	2.913	4.2351E-03
6.246	1.353	.471	.513	0.000	.662	.449	.268	.762	0.000	3.124	4.2537E-03
6.447	1.397	.503	.550	0.000	.707	.479	.286	.813	0.000	3.337	4.2648E-03
6.649	1.440	.537	.588	0.000	.754	.512	.306	.868	0.000	3.565	4.2841E-03
6.850	1.484	.572	.627	0.000	.803	.545	.325	.924	0.000	3.795	4.2961E-03
7.052	1.528	.606	.657	0.000	.851	.578	.345	.980	0.000	4.026	4.3006E-03
7.253	1.571	.644	.710	0.000	.904	.614	.366	1.041	0.000	4.280	4.3210E-03

CALCULATED FLAT PLATE FRICTIONAL RESISTANCE COMPONENTFOR SHIP SCALE APPENDAGES BASED ON LOCAL REYNOLDS NUMBER-IN LBS

THE APPENDAGE FLAT PLATE FRICTION COEFFICIENT=FRICT. DRAG(APP)/((DENSITY/2.)*(VEL.)*(VEL.)*(APPENDAGE WETTED SURFACE))

VS-KNOTS	VRL	RUDDER	STRUT	FIN	SHAFT	BOSS	MAIN	BILGE	SKFG	TOTAL	COEFFICI
12.000	.524	5.8163E+02	6.5739E+02	0.	8.3128E+02	5.5481E+02	3.2240E+02	9.8922E+02	0.	3.9367E+03	2.3925E-0
13.000	.567	6.7548E+02	7.6296E+02	0.	9.6622E+02	6.4441E+02	3.7451E+02	1.1507E+03	0.	4.5743E+03	2.3687E-0
14.000	.611	7.7596E+02	8.7591E+02	0.	1.1108E+03	7.4074E+02	4.3032E+02	1.3239E+03	0.	5.2573E+03	2.3474E-0
15.000	.655	8.8799E+02	1.0017E+03	0.	1.2722E+03	8.4731E+02	4.9255E+02	1.5173E+03	0.	6.0191E+03	2.3411E-0
16.000	.698	1.0004E+03	1.1280E+03	0.	1.4342E+03	9.5468E+02	5.5503E+02	1.7117E+03	0.	6.7840E+03	2.3191E-0
17.000	.742	1.1149E+03	1.2544E+03	0.	1.5993E+03	1.0640E+03	6.1863E+02	1.9098E+03	0.	7.5629E+03	2.2902E-0
18.000	.786	1.2414E+03	1.3983E+03	0.	1.7819E+03	1.1840E+03	6.8897E+02	2.1290E+03	0.	8.4244E+03	2.2755E-0
19.000	.829	1.3720E+03	1.5446E+03	0.	1.9703E+03	1.3095E+03	7.6152E+02	2.3554E+03	0.	9.3172E+03	2.2577E-0
20.000	.873	1.5085E+03	1.6975E+03	0.	2.1675E+03	1.4399E+03	8.3742E+02	2.5974E+03	0.	1.0243E+04	2.2410E-0
21.000	.917	1.6509E+03	1.8570E+03	0.	2.3734E+03	1.5760E+03	9.1665E+02	2.8400E+03	0.	1.12[illegible]4E+04	2.2753E-0
22.000	.960	1.7993E+03	2.0231E+03	0.	2.5879E+03	1.7178E+03	9.9918E+02	3.0982E+03	0.	1.2225E+04	2.2105E-0
23.000	1.004	1.9536E+03	2.1957E+03	0.	2.8111E+03	1.8651E+03	1.0850E+03	3.3668E+03	0.	1.3277E+04	2.1965E-0
24.000	1.047	2.1137E+03	2.3748E+03	0.	3.0428E+03	2.0181E+03	1.1741E+03	3.6458E+03	0.	1.4369E+04	2.1832E-0
25.000	1.091	2.2797E+03	2.5602E+03	0.	3.2831E+03	2.1767E+03	1.2664E+03	3.9351E+03	0.	1.5501E+04	2.1705E-0
26.000	1.135	2.4514E+03	2.7521E+03	0.	3.5318E+03	2.3407E+03	1.3619E+03	4.2348E+03	0.	1.6673E+04	2.1584E-0
27.000	1.178	2.6142E+03	2.9340E+03	0.	3.7676E+03	2.4963E+03	1.4525E+03	4.5191E+03	0.	1.7784E+04	2.1349E-0
28.000	1.222	2.8120E+03	3.1549E+03	0.	4.0544E+03	2.6854E+03	1.5626E+03	4.8648E+03	0.	1.9134E+04	2.1358E-0
29.000	1.266	3.0233E+03	3.3908E+03	0.	4.3607E+03	2.8873E+03	1.6802E+03	5.2343E+03	0.	2.0577E+04	2.1412E-0
30.000	1.309	3.2312E+03	3.6228E+03	0.	4.6623E+03	3.0860E+03	1.7960E+03	5.5982E+03	0.	2.1997E+04	2.1389E-0
31.000	1.353	3.4655E+03	3.8842E+03	0.	5.0023E+03	3.3099E+03	1.9264E+03	6.0086E+03	0.	2.3597E+04	2.1488E-0
32.000	1.397	3.7027E+03	4.1487E+03	0.	5.3466E+03	3.5366E+03	2.0585E+03	6.4242E+03	0.	2.5217E+04	2.1551E-0
33.000	1.440	3.9561E+03	4.4312E+03	0.	5.7145E+03	3.7788E+03	2.1996E+03	6.8686E+03	0.	2.6949E+04	2.1656E-0
34.000	1.484	4.2118E+03	4.7162E+03	0.	6.0860E+03	4.0233E+03	2.3420E+03	7.3174E+03	0.	2.8697E+04	2.1724E-0
35.000	1.528	4.4687E+03	5.0024E+03	0.	6.4593E+03	4.2688E+03	2.4850E+03	7.7685E+03	0.	3.0453E+04	2.1755E-0
36.000	1.571	4.7512E+03	5.3170E+03	0.	6.8698E+03	4.5389E+03	2.6424E+03	8.2648E+03	0.	3.2384E+04	2.1868E-0

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